The Impact of Sex, Familial Sinistrality, and Hormone Levels on Visuospatial Ability and Strategy Use in Right-Handers

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To Amelia and Geoffrey

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Abstract

The Impact of Sex, Familial Sinistrality, and Hormone Levels on Visuospatial Ability and Strategy Use in Right-Handers

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Cognitive sex differences are greatest in spatial areas, with men demonstrating more efficient solution strategies and greater overall performance than women on some tasks. An exception to this pattern has been found in a subgroup of women identified by individual and family handedness (right-handed with at least one left-handed biological relative)--factors that may be linked to genetic influences on brain organization. These women not only exhibit equal ability to men but also appear to use similar strategies.

Normal fluctuations in estrogen during the menstrual cycle have also been associated with performance variations within women. Spatial performance may peak at menses, when estrogen is relatively low. Conversely, verbal performance may be best during phases when estrogen is relatively high. The current study examined the effect of sex, family handedness, and hormone (estrogen and testosterone) levels on cognitive performance and strategy use. Although the role of each of these factors was considered independently, the primary focus of this study was to explore possible interactions between them.

Fifty subjects, grouped as to sex and family handedness, attended two test sessions. For females, sessions were timed to correspond with the late follicular and menstrual phases of the menstrual cycle. A repeated measures MANOVA

was significant for sex F (13,34)= 4.46 ($p<.0001$), with men outperforming women on mental rotation and finger tapping and women outperforming men on the Grooved Pegboard. A MANOVA conducted on non-repeated measures found a significant effect for family handedness, favoring FS+ women, on the Rey Osterrieth Complex Figure (recall and strategy).

No overall main effect for menstrual cycle phase was found for women. However, a significant interaction was found between cycle phase and family handedness, with FS+ women performing better during the menstrual phase of their cycle and FS- women showing better performance at mid-cycle. This tendency was seen across spatial, verbal, and motor measures. These results may offer some insight into why findings regarding menstrual cycle effects have been inconsistent and suggest that it may be important to consider between-subject factors when looking at any possible within-subject effects such as those that may occur over the menstrual cycle.

1. Background and Review of the Literature
1.1 Introduction

Data have long-supported the notion that men perform better on visual-spatial tasks while women tend to do better on verbal ones (Kinsbourne, 1978; Lezak, 1995; Maccoby & Jacklin, 1974). Of these differences, the greatest between the sexes is on visuo-spatial ability (Maccoby & Jacklin, 1974), with men demonstrating greater use of more efficient visually-based (right-hemisphere) strategies and women showing greater reliance on verbally-based (left-hemisphere) strategies to solve spatial problems (Pezaris and Casey, 1991). Research in this area continues to address questions as to the nature of these differences and why they exist. Possible explanations include differences in how males and females are socialized (Pearson & Ferguson, 1989) and/or biological factors such as inherent brain organization (Reite, Cullum, Stocker, Teale & Kozora, 1993; Willerman, Schultz, Rutledge, & Bigler, 1992), genetic (Casey & Brabeck, 1989; 1990), hormonal (Gouchie & Kimura, 1991; Kimura, 1999), and maturational (Sherman, 1978) differences between the sexes.

Although reliable differences between men and women have been found in a number of areas, the variation within a sex can also be as wide as the variation between women and men. There is evidence that some women show a pattern of verbal-spatial performance that favors spatial tasks (and score in the same spatial range as men) and likewise there are men who show a verbal advantage and perform as well as women (Kimura, 1999). An exception to male visual-spatial superiority has been found in a subgroup of women identified by

individual and family handedness (right-handed with at least one left-handed immediate biological relative)--factors that may be linked to genetic influences on brain organization (Annett, 1995b). These women not only exhibit equal ability to men in overall performance but, importantly, appear to use the same solution strategies as men (D'Andrea, 1998).

In addition to findings that some women show a pattern of verbal-spatial performance typically attributed to men, normal hormonal fluctuations during the menstrual cycle have been associated with performance variations within women. Spatial performance has been found to peak during menstruation, when estrogen is relatively low, and verbal performance appears to be at its best during the late follicular phase, when estrogen is relatively high (Hampson & Kimura, 1992). Two gonadal hormones in particular, estrogen and testosterone, have been implicated in spatial abilities (Hausmann, Slabbekoorn, Van Goozen, Cogen-Kettenis and Gunturkun, 2000), with better mental rotation performance in women associated with relatively high testosterone and low estrogen levels. High testosterone levels have been linked with higher math and spatial task performance (Gouchie and Kimura, 1991; Kimura, 1992; Shute, Pellegrino, Hubert & Reynolds, 1983) in girls but lower performance in boys (Moffat and Hampson, 1995), suggesting that there may be certain levels of testosterone between the average female level and average male level that is optimal for spatial ability. However, there have been some inconsistencies in the literature, and this phenomenon has not been adequately studied. In particular, previous studies have not taken into account the importance of spatial aptitude and strategy preferences that may be, at least in part, genetically mediated. Given that hormones such as estrogen appear to impact spatial and verbal abilities

differently, individual differences in strategy preference may exert an effect on how much and in what direction hormone fluctuations impact spatial performance.

Considering all of the above-mentioned factors that may contribute to individual differences in visuospatial ability highlights the complexity of putting together a unifying theory that takes into account the various potential determinants of spatial performance including sex, cerebral lateralization patterns that may be linked with handedness and family handedness, strategy preference, and hormone levels. However, as complicated as this evolving picture is, it is important for research looking at individual differences to consider all of these factors. Failure to do so has the potential to have a negative effect upon findings and makes the whole of research in this area difficult to interpret.

The following review will examine the pertinent literature on between-sex cognitive differences, with a particular emphasis on visuospatial ability. The relationship between sex, handedness, family handedness, and lateralization will be considered in examining why some women may be an exception to the "male superiority" on spatial tasks. The theoretical basis for identifying this target group of women will also be detailed. Throughout, particular attention will be paid to differences in cognitive strategies as they relate to this study. A section will also be dedicated to the review of studies considering the role of hormones in brain organization, handedness, and spatial performance. Finally, the importance of understanding individual differences in visuospatial ability and how various factors may impact this will be addressed.

1.2 Sex-Based Cognitive Differences

Over the years, there has been much interest in identifying cognitive differences between the sexes and attempting to understand what underlies them. Sex-based differences emerge in a number of cognitive areas (Kinsbourne, 1978; Lezak, 1995; Maccoby & Jacklin, 1974; Sherman, 1978). On the one hand, men tend to do better at some visuospatial tasks, particularly mental rotation and some aspects of visuospatial organization. On average, they also outperform women in mathematical reasoning (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; Maccoby and Jacklin, 1974; Raymond and Benbow, 1986). On the other hand, women show an advantage on verbal abilities (Halpern, 1992) such as verbal fluency and articulatory tasks (Kimura, 1987), spelling and grammar (Kimura, 1999) and verbal recall which may be, in part, attributable to superior ability to organize verbal material (Kramer, Delis & Daniel, 1988). In addition, women may be better than men at recalling emotionally-charged autobiographical events (Davis, 1999) and performing arithmetic (Halpern, 1996). Motorically, men outperform women on simple speeded motor tasks such as finger tapping (Bornstein, 1985; Dodrill, 1979; Ruff and Parker, 1993). However, significant sex differences disappear on more challenging speeded sequential finger movement tasks (Nicholson and Kimura, 1996) and women outperform men on speeded fine motor tasks such as the Grooved Pegboard Test (Bornstein, 1985; Ruff and Parker, 1993).

Of these performance differences between the sexes, perhaps the best documented involve certain aspects of visuo-spatial ability (Halpern,1996; Linn and Petersen, 1985; Maccoby and Jacklin, 1974). Most studies report a small but significant and reliable (Halpern 1996) male advantage for a wide variety of

spatial tasks involving spatial orientation (e.g. mental rotation) (Halpern, 1992; Linn and Petersen, 1985; Stumpf, 1993), spatial visualization (e.g. mental paper folding tasks) (Fennema & Tartre, 1985; Maccoby & Jacklin, 1974) and spatial perception (e.g. rod and frame type tasks) (for review see Kimura, 1999). Of these, the largest and most consistent sex differences have been found on mental rotation tasks (Linn and Petersen, 1985; Pearson and Ferguson, 1989). Although there has been support for the notion that these differences are the most meaningful and pronounced as task difficulty increases (Sanders, Soares, and D'Aquila, 1982), work comparing performance on separate versions of mental rotation tasks with stimuli of varying difficulty has found significant sex differences for easier as well as more difficult items (Peters, 1995). In addition, sex differences have been demonstrated using rotation tasks involving two-dimensional as well as three-dimensional stimuli (Collins and Kimura, 1997).

A male advantage has been found for spatial activities that are relevant to navigational ability such as maze-learning tasks (Moffat, Hampson, and Hatzipantelis, 1998), map reading, and route learning (Galea & Kimura, 1993; Schofield and Kirby, 1994)-- suggesting to some that these differences may have evolved due to a need for males to be able to travel over large areas in order to hunt for food (Kimura, 1999). In addition, differences between males and females in mental rotation and visualization ability may underlie much of the sex differences found in mathematics aptitude (Fennema & Tartre, 1985). For example, much of the difference between men and women on math SAT scores may be mediated by spatial abilities such as those tapped by mental rotation tasks (Casey, Nuttall and Pezaris, 1997; Casey, Nuttall, Pezaris and Benbow, 1995).

It is important to note, however, that sex differences may not exist for all spatial tasks (Alyman and Peters, 1993; Halpern and Wright, 1996; Linn and Petersen, 1985) and not all spatial tasks favor males. Women have been reported to show a recall advantage for the spatial location of objects in an array (Eals & Silverman, 1994; McBurney, Gaulin, Devineni, & Adams, 1997), although this advantage may be task-dependent. In a study by James and Kimura (1997), women performed better than men in an object exchange task in which remembering the identity of the object was critical to success. However, in an object location shift task in which objects were placed on areas of the page where no object had been previously, sex differences were not found. One possible explanation for this is that the women may have outperformed men in the object exchange task due to their greater verbal ability rather than to a specific spatial advantage per se (for example, by successfully attaching verbal labels to the objects). Verbal ability may be less advantageous for the object location shift task that places a higher demand on visualizing specific locations.

Work using regional cerebral blood flow has shown that when individuals perform visual memory tasks that tax working memory, prefrontal areas are activated bilaterally. However, in a study by Ungerleider, Courney, and Haxby (1998), it was found that right hemisphere activity diminished over time and left increased over time, suggesting that right-hemisphere spatial analysis is more difficult to maintain than left-hemisphere symbolic/verbal representation. This could provide some basis for understanding why women may have a delayed memory advantage for visual material that can be remembered using a verbal "left hemisphere" approach whereas men, who have a visuospatial organization advantage, have an advantage on tasks which are not easily verbally encoded. As

will be discussed later in this paper, this underscores the need to fully understand the nature of the task at hand and the particular strategy used to solve it when looking at individual differences in spatial ability.

A great deal of work has been done to examine the role of socialization in cognitive performance differences between women and men, and there is a significant body of evidence that socialization practices continue to impact sex differences (for a discussion, see Halpern, 1992). Much of this research has focused on differences between how males and females are raised including the types of academic and recreational interests that are encouraged and how this impacts expectations individuals have about themselves and others. Men and women may, in fact, have different expectations about their own ability to execute spatial tasks and these expectations have been shown to influence performance significantly (Sharps, Welton, and Price, 1993).

While factors that are not directly related to innate visuospatial ability can influence whether or not optimal performance is achieved, biological factors that influence sex-based cognitive differences are also important to consider. For a number of reasons, there has been a shifting away from explanations that are entirely environmentally-based. First, there is significant support for the notion that environmental factors cannot entirely account for between-sex differences in ability such as in math where boys are more likely to excel (Benbow, 1990; Benbow et al.., 2000; Hampson, Rovet, & Altmann, 1998; Raymond and Benbow, 1986; Saccuzzo, Craig, Johnson, and Larson, 1996). Along similar lines, environmental factors have failed to entirely account for within-sex variability in visuo-spatial organization, problem solving, and memory in women (Casey, Nuttall, & Pezaris, 1999; D'Andrea, 1998). For example, in a study by D'Andrea

(1998) it was found that women with significant exposure to visuospatial tasks through math and science coursework, believed to be one vehicle through which males gain a spatial advantage, did not perform better on a variety of visuospatial tasks than women in verbally-oriented fields such as the humanities. Secondly, there is increasing evidence that biological factors including genetic (Annett, 1985, 1995a,1999b) and/or hormonal influences (Hampson & Kimura, 1988) on brain organization are involved in sex-based cognitive differences. Thirdly, there has been, perhaps, some greater acceptance for the idea of celebrating diversity and individual strengths and weaknesses, allowing researchers of sex-related cognitive differences to be less fearful of considering explanations that are not entirely environmentally based (for a discussion of the controversial nature of studying biological bases for sex differences see Halpern, 1992 and 1996).

When establishing the possibility of a biological basis for cognitive sex differences, it is important to consider at what age differences emerge in children and how stable they are over time. The majority of cognitive differences between the sexes do remain reasonably stable throughout the lifespan. The work of Benbow et al.. (2000) lends support to the notion that males have a greater aptitude for mathematical reasoning, and that this remains stable into adulthood. Sex differences on spatial and motor tasks described for young adults have also been found in middle aged and older adults (Ylikoski et al, 1998). Sex differences on finger tapping (men outperform women), and grooved pegboard (women outperform men) tasks remain throughout all age groups between 16 and 70 years (Ruff and Parker, 1993). Stumpf and Eliot (1995) found the same male/female performance pattern on spatial tasks in children aged 12-17 as has

been cited in adults, with males having a particular advantage on mental rotation but females doing better on visual memory tasks.

The age at which expected sex differences emerge tends to be highly task-dependent. Expected sex differences have been found fairly early in development for some tasks. For example, boys begin to outperform girls on map reading tasks as young as age 5 (Liben & Downs, 1993). However, some research has failed to reveal a male advantage (Pontius, 1997b; 1997a), or has even shown a female advantage (Karapetsas and Kantas, 1991; Karapetsas and Vlachos, 1992; Waber, Bernstein, and Merola, 1989) for some other spatial tasks in studies with young children aged 12 and under. Although similar research results have been cited as evidence that societal influences are the primary cause of cognitive sex differences, a number of researchers have suggested that maturation differences also come into play (Karapetsas and Kantas, 1991; Karapetsas and Vlachos, 1992; Waber, Bernstein, and Merola, 1989). Most individuals do not achieve optimal performance on some tasks until late adolescence when areas of the brain such as cerebellum and frontal cortex fully mature (Davies & Rose, 1999; Leiner, Leiner & Dow, 1986). In addition, the degree to which different processes may be influenced by the hormonal milieu is important to consider. As will be discussed further later in this paper, the fact that some spatial differences may not emerge until puberty has been cited as possible support for the notion that gonadal steroids may play a role in these differences (Hampson, 1995). For example, it has been argued that spatial differences in many areas appear at an age when boys begin producing greater levels of testosterone (for a review, see Shute, Pellegrino, Hubert, & Reynolds, 1983).

In sum, men generally perform better on spatial tasks and women do better on some verbal ones. Cognitive sex differences are greatest in spatial areas, particularly for tasks involving spatial orientation, spatial visualization and spatial perception. While it is likely societal influences continue to impact these differences, there is considerable evidence that biological factors also play a significant role. Importantly, sex differences may not exist for all spatial tasks and maturational factors also likely influence when expected sex differences emerge. Waber, Bernstein, and Merola (1989), who found 5th grade girls to do better at organizing the Rey-Osterrieth Figure than boys, further the maturation argument by suggesting girls may be better than boys at utilizing verbally-oriented strategies, giving them an advantage at ages when spatial skills have yet to mature. Thus, it is reasonable that factors such as the demands of a particular task, the age when a task can be optimally performed, and the ability for a task to be solved by different strategies have particular relevance when studying cognitive sex differences. The following section will look at the importance of understanding the cognitive demands of visuospatial tasks and what alternative strategical approaches men and women may use to solve them.

1.2.1 Sex, Visuospatial Tasks, and the Brain

As discussed in the previous section, significant cognitive sex differences favoring men have been found for a number of visuospatial tasks. Under the umbrella of "visuospatial tasks," however, resides a wide range of skills of varying degrees of complexity. Various tasks tap different, albeit often overlapping, abilities (Rosser, 1994; Simons & Wang, 1998) involve different networks in the brain (Belger, Puce, Krystal, Gore, Godman-Rakic, & McCarthy,

1998), and vary in the degree to which they can be successfully solved using different problem-solving strategies. As Rosser (1994) points out, "spatial cognition is more reasonably envisioned as a multidimensional conglomerate of separate cognitions" with "different developmental histories, patterns of individual variation, and interconnections among them." (p. 276-277).

Even when visuospatial tasks have been broken down into components such as spatial orientation, spatial visualization, and spatial perception, researchers have continued to differ as to which of these components they assign various tasks. Thus, some of the inconsistencies in the literature examining individual differences in visuospatial ability may be attributable to problems in how different cognitive areas are defined, what specific abilities are said to be measured by a specific test or task, or the use of composite measures that obscure significant differences. Task factors not directly related to spatial ability can also influence spatial performance and, therefore, may need to be considered. For example, sex differences in motoric ability (O'Boyle, Hoff, and Gill, 1995) and/or personality (Meurling, Tonning-Olsson, and Levander, 2000; Stumpf, 1993) may play a role in whether or not a particular task shows an effect for sex and in what direction. In order to understand individual differences in spatial ability such as those associated with sex, it is important to consider what the specific demands are for a particular task, what strategies might be used, and how these relate to the brain.

Findings that women and men differ in visuospatial performance have been examined in research looking at differences in locations in the brain utilized during these tasks. A number of hypotheses have been set forth including sex-based differences in intrahemispheric organization, greater functional

lateralization in males than females, and sex differences in preferences for particular problem solving strategies (verbally-mediated vs. spatially-mediated).

In general, the right cerebral hemisphere is linked with visuospatial ability. Early (Levy-Agresti & Sperry, 1968) work in this area revealed differences in how the right and left hemispheres are able to visualize in three dimensions, with the right hemisphere superior at seeing the gestalt and the left better at looking at individual features and properties of the image. However, although spatial tasks have been viewed as being solved by the "right hemisphere" this is not exclusively the case. In addition, differences in areas used within the right-hemisphere may depend on the type of visual stimulus. Desrocher, Smith and Taylor (1995) found that manipulation of letters involved anterior areas as compared with abstract figure rotation that relied more on posterior temporal areas in as measured by EEG. Posterior systems (occipital-parietal) may be more involved in visuospatial abilities, whereas the temporal lobe more involved in semantic processing (Wilson, Clare, Young, & Hodges, 1997). Additionally, posterior areas like the cerebellum, once thought to be mainly involved in sending signals to motor areas, are now believed to send projections to prefrontal cortex--suggesting involvement in cognitive processing such as the manipulation of information or ideas and maintaining mental images (Leiner, Leiner & Dow, 1986 &1995). Leiner, Leiner & Dow (1986) have suggested the possibility that individual differences in cognitive ability may correlate with posterior/anterior fibers between the cerebellum and frontal association cortex. Furthermore, there is likely an interaction between task, sex, performance, and brain activation. When Kimura (1983; 1987) looked at the neuropsychological performance of patients with brain damage limited to the left hemisphere, she

noted that aphasia and apraxia in male patients tended to result from posterior lesions whereas females tended to be from anterior lesions.

Performance differences between men and women on visual and verbal cognitive tasks have been studied along with sex differences in locations in the brain utilized during these tasks. The idea that women are less lateralized than men has long been considered, and researchers using anatomical and physiological measures have been interested in looking at the relationship between task performance and lateralization differences between the sexes. However, can lateralization differences entirely account for these differences? Willerman, Schultz, Rutledge & Bigler (1992) looked at hemisphere size using MRI studies of normal young adults. In men, they found that a relatively large left hemisphere predicted better verbal than non-verbal ability. In women, a relatively larger left hemisphere predicted better non-verbal than verbal ability. Pointing to research in the area of sex differences that indicates that men with left hemisphere lesions tend to have a greater decline in Performance IQ than Verbal IQ, whereas women with left-sided lesions tend to show a decline in both Verbal and Performance IQs (McGlone, 1977), Willerman et al. (1992) felt that the results of their study combined with this observation lends support to the idea that neural structures underlying women's non-verbal problem solving are distributed to both hemispheres.

While degree of lateralization may interact with sex when predicting cognitive abilities, a full understanding of this relationship has yet to be determined. In general, high visuospatial (Ray, Newcombe, Simon, and Cole, 1981; Wendt and Risberg, 1994) and math (O'Boyle, Alexander & Benbow, 1991) aptitude has been associated with greater right than left hemisphere activity,

with the opposite pattern found in those with low aptitude. However, some sex differences have been reported. O'Boyle, Benbow, and Alexander (1995) found that gifted females tended to demonstrate more bilateral organization, whereas gifted males tended to be more right-lateralized. Men who are better at challenging spatial tasks may tend to be more lateralized to the right, while those better at verbal tasks weakly lateralized to the left (White, Green, and Steiner, 1995). In another study, high bilateral temporal lobe glucose metabolism rates have been linked to better math performance in men, but not women (Haier and Benbow, 1995). Additionally, not all researchers have found a correlation between sex and lateralization (Wendt and Risberg, 1994; Herman, Grabowska, and Dulko, 1993).

Thus, simply looking at the degree of lateralization in males and females cannot wholly account for sex differences in spatial performance or in VIQ-PIQ splits after lateralized lesions.

Turkheimer et al. (1993), in their quantitative analysis of sex differences in the effect of lateralized brain lesions, state that:

> The hypothesis that the gender difference is largely the result of differences in the degree of lateralization in males and females cannot account for the results, because a statistical model in which the genders have the same degree of lateralization fits the data as well as a model in which the genders are allowed to differ. (p. 471).

Turkheimer et al. (1993) go on to state that not only do lateralization differences fail to explain sex differences in VIQ-PIQ splits after lateralized lesions adequately, but explanations involving within-hemisphere differences do

not fit their data either. The theory that did fit their data was the explanation that women rely more on verbal strategies to solve spatial problems than men. Strategy differences have been considered to be a possible explanation for this phenomenon by other investigators (Inglis and Lawson, 1982; Turkheimer, Farace, Yeo & Bigler, 1993; Wendt and Risberg, 1994). The following will examine more closely the role of strategy in cognitive performance differences between the sexes.

1.2.2 Problem-Solving Strategies

In order to establish a role for strategy in cognitive performance differences between the sexes, it is necessary to identify a general relationship between strategy and performance and to show that there are convincing sex differences in strategy preference and use. Strategy is an important factor contributing to quality of performance in a number of spatial tasks--many of which can be solved by a verbal ("left hemisphere ") approach or a more visual/gestalt ("right hemisphere") approach (De Vega et al., 1996; Casey et al., 1991). It is interesting to note that the "left hemisphere" approach is distinctly different from the "right hemisphere" approach even when vision is removed from the equation (Iverson, 1999). Thus, these two cognitive approaches are not necessarily tied to visual processing per se. Although providing strategy training can be effective in improving performance, those who naturally use visual approaches generally outperform those who use verbal or no specific strategy performance (Schofield and Kirby, 1994; Taylor, Naylor & Chechile, 1999).

Differences in visuospatial aptitude have been associated with strategy use in both men and women. For example, Schofield and Kirby (1994) looked at

ability using a topographical map task. They tested 188 male Australian army personnel using a spatial relations task (mental rotation), spatial visualization task (mental paper folding), and a questionnaire aimed at assessing preference for visual vs. verbal learning strategies for a number of items (e.g. preferring diagram vs. verbal instructions). They found that spatial visualization and a preference for visual learning predicted high ability at the task that involved finding a location on a topographical map after having been shown a three-dimensional model of the target area to be found in the map. Although this study only used men, greater use of holistic (right-hemisphere) strategies have also been linked to increased visuospatial performance in women (D'Andrea, 1998).

A number of researchers have found differences in strategy use between men and women on spatial tasks (Meurling et al, 2000; Sandstrom, Kaufman, and Huettel, 1998), with women tending to be more reliant on left-hemisphere/verbal strategies on spatial tasks. Linn and Petersen (1985) proposed that sex differences on mental rotation could be strategy-related, suggesting an inefficient piecemeal analytic strategy more often adopted by women may underlie sex differences.

Work looking at sex differences in mental rotation strategy has been done using an interference paradigm. Pezaris and Casey (1991) used interference tasks under the assumption that if an individual is using a visual strategy he or she will be more inhibited by a spatial interference. If using a verbal-mediated strategy, on the other hand, he or she will be more disrupted by verbal interference since the same processing resources will be competing (see Baddeley, 1990 & 1999). Pezaris and Casey (1991) found that boys outperformed girls on mental rotation tasks. The results of their study also showed that girls

were more susceptible to verbal interference, and boys to visual. They therefore concluded boys used more visual-spatial (right-hemisphere) strategies and relied less on verbal (left hemisphere) strategies than girls in mental rotation problems.

Additional support for the importance of considering strategy when evaluating sex differences comes from behavioral performance measures involving navigational problems. Women are more likely than men to use verbal strategies such as focusing on features or using words to describe spatial relationships (Inglis and Lawson, 1982; Turkheimer, Farace, Yeo & Bigler, 1993). While women prefer to employ topographical landmarks in route-finding tasks, men usually gravitate toward spatial direction and distance strategies (e.g. Galea & Kimura, 1993, Beatty & Troster, 1987) and these strategies parallel recall performance for topographical vs. spatial information (Galea & Kimura, 1993).

Although much of the work on sex differences in spatial ability have focused on tasks with relatively large (e.g. mental rotation) or moderate (e.g. spatial visualization) sex differences favoring males, a number of studies have been done using a visual memory task, the Rey-Osterrieth Complex Figure Test. The Rey-Osterrieth figure is particularly interesting because, although it is typically viewed as a test of immediate and delayed recall for spatial material, several scoring systems have been developed to examine figure copy strategy and the role it plays in recall (Bennet-Levy, 1984; Visser, 1973; Waber & Holmes, 1986; Hamby, Wilkins & Barry, 1993). Many studies have found that optimal (holistic) strategy use tends to lead to better encoding of the figure (Chen, Cermak, Murray and Henderson, 1999; Dawson and Grant, 2000; Kosc and Jariabkova, 1998).

Results of analyses aimed at addressing the question of whether or not there are differences between the sexes on this task have been mixed and perhaps marred by inconsistent criteria for evaluating performance. Significantly, those studies that neglected to evaluate strategy found no sex differences or only slight differences that did not reach statistical significance. Berry, Allen, & Schmitt (1991) and Boone, Lesser, Hill-Guitierrez, Berman, and D'Elia (1993) found no sex differences in a sample of healthy elderly people, but did not evaluate copy strategy. Rosselli and Ardila (1991), again looking at the normal elderly, found a trend for men doing better than women on the Rey, but they did not look at organization and results in this area did not reach statistical significance.

Casey, Winner, Hurwitz & DaSilva (1991) did find an effect of sex on recall scores on the Rey in their study that considered processing style. In another study by Bennet-Levy (1984) which also looked at differences in strategy, it was found than normal men and women differed in strategy, with men doing better on measures of symmetry, continuation, and strategy total. Differences in recall appeared to be due to these differences in strategy, as there were no memory differences when the effect of strategy was partialed out.

Casey, Winner, Hurwitz, and DaSilva (1991) did a study to see if normal people's individual processing style has an effect on accuracy of recall. The assumption underlying the study was that all people have a preferred style in which they process information, either by using verbal strategies or visual strategies, or, rather, in words or in images. Each of these processing strategies would be based on different systems in the brain. Categorical relations like "next to" would be representative of a left hemisphere function whereas those pieces of

information about the shape or size of an object would be a right hemisphere function. When looking at this task from the dual processing theory point of view, therefore, the overall structure of the Rey-Osterrieth Complex Figure would be a right hemisphere function, and the details would be left. This breakdown, however, becomes more complex if you also consider that the person may have a preferred way of approaching the figure, either with a verbal strategy or a visual one. Given the fact that people tend to use the strategy that they prefer, if they can, the only time we can assume that visual strategies are being used is when the task at hand necessitates the use of that particular strategy.

There is evidence that the Rey-Osterrieth figure does place a demand on spatial ability. A number of studies (Strauss and Spreen, 1990; Tombaugh and Hubley, 1991) have shown that the Rey does not lend itself to phonetic encoding and is, therefore, more likely to be measuring the targeted visuospatial skills. Additional support for this notion comes from Casey et al.'s (1991) study. Subjects were given either the Rey-Osterrieth or the Taylor Figure Test. The Taylor Figure has long been thought to be equivalent to the Rey Figure, and is often used for re-test comparisons (Lezak, 1983). However, the Taylor figure has been found to be more easily verbally encoded (Casey, Winner, Hurwitz, and DaSilva, 1991) than the Rey-Osterrieth figure. Subjects were given three minutes to copy the given stimulus figure and then were given three additional minutes to draw it from memory. After this, they were told to indicate the strategy that they used.

Casey et al. (1991) were interested to see if subjects used their preferred processing style on the Rey Figure. This was assessed by comparing their

preferred processing style, as determined by a sentence picture verification task, with the style that they reported using on the Rey-Osterrieth Figure. Eighty-two percent of the visualizers and 81% of the verbalizers used a visual strategy on this task for the recall. People who naturally used a visual approach did better on the recall than those who didn't. Interestingly, this advantage did not generalize to the Taylor Figure. On the Taylor figure, half of the verbalizers were able to stay with their preferred processing style. Recent work has also found that women outperformed men on delayed recall for the Taylor figure, but men did better on the Rey (Vingerhoets, Lannoo, & Wolters, 1998). This is particularly interesting in light of findings that females have been shown to use more left-hemisphere processing/verbal encoding strategies than males (Birkett, 1980) and underscores the importance of careful task selection in what we refer to as verbal and visuospatial.

Thus, it is important not to neglect strategy differences when examining sex-based cognitive differences. It may be important to note that if women tend to use verbal strategies more readily than visual ones, this may in part account for their general poorer performance when compared to men.

In examining sex-based cognitive differences, the following points are summarized. Men generally outperform women on visual-spatial tasks and women tend to outperform men on some verbal and memory tasks. Although visuospatial ability appears to be the greatest cognitive difference between the sexes, men do not have an advantage on all visuospatial tasks. Environmental factors likely impact sex-based cognitive differences, but there is considerable evidence that biological factors also play a significant role. Understanding individual differences in spatial ability requires understanding what skills are

needed for a given task, which of those skills account for differences, how many ways a task can be solved, and the role of strategy in performance. Finally, some women perform as well as men on the visuospatial tasks that typically show the greatest differences between the sexes and differences within sex tend to be larger than those between the sexes. Handedness, like sex, has been associated with individual differences in brain organization and visuospatial performance. The following section will examine a possible link between handedness and family handedness when looking at within-sex visuospatial performance differences.

1.3 Handedness and Family Handedness

The possibility of a relationship between handedness and spatial ability has often been considered using comparisons of right- and left-handers. However, handedness may be a continuous rather than distinct variable (Annett, 1996, 2000; Gangestad & Yeo, 1994), making it more difficult to make clear distinctions between handedness groups. Furthermore, the relationship between handedness, brain organization, and performance is increasingly viewed as a much more complex one in which strategy preference, inheritance patterns, and sex may also play a role (Casey, Winner, Benbow, Hayes & DaSilva, 1993).

Right-handedness has long been more prevalent in humans than left-handedness. Anthropological evidence has been provided by studies of skull injuries in the earliest hominids, which indicate right-handed attackers, and stone age tools appearing to be made predominantly by right-handed tool makers. Approximately 90-95% of adults are right-handed (Lezak, 1995) and of

those, the majority (90-98%) have typical cerebral lateralization with language ability located in the left hemisphere and visuospatial ability located in the right hemisphere (McManus, 1999). Although the majority of left-handers, like right-handers, have language in the left hemisphere, a higher percentage of left-handers (20-30%) do have right-hemisphere language. In addition, left-handers are sometimes found to have bilateral language, which is rare in right-handers. Thus, left-handers are not a distinct group in terms of functional lateralization. This section will review work looking at a possible relationship between handedness and spatial ability. Theories considering genetic influences on handedness will be considered. Emphasis is placed on Annett's theory, particularly in regard to predictions that familial handedness may interact with handedness to influence spatial ability in women.

1.3.1 Handedness and Spatial Ability

The possibility of a relationship between handedness and spatial ability has long been considered. In a much-cited report, Levy (1969) proposed that left-handed individuals, presumed to have more bilateral representation of language, would do less well on visual perceptual tasks than right-handers. This theory is supported, in part, by her finding that right-handed males outperformed left-handed males on performance subtests of the Wechsler Adult Intelligence Scale (WAIS) in the absence of significant differences on verbal measures. While some other studies have shown superior spatial ability in right-handers (see McKeever, 1986), many others have found no significant difference in spatial ability between right- and left-handers or have even found superior performance in left-handers (for a review, see Sanders, Wilson, and Vandenberg, 1982). Reasons for these inconsistencies likely arise from a number of factors including task selection, not

differentiating between highly lateralized and mixed lateralized left-handers (Snyder & Harris, 1993), and, in some cases, not using women--a problem given the link between sex and lateralization. There is evidence that sex interacts with handedness (Annett, 1992; Sanders, Wilson, and Vandenberg, 1982) and that failure to account for this interaction has resulted in inconsistencies in the literature (Harshman, Hampson, and Berenbaum, 1983; Snyder and Harris, 1993).

Methodological difficulties in the handedness research have also included inconsistencies in how handedness groups are defined and how handedness is assessed. Various handedness groupings have been used including right vs. left (Inglis & Lawson, 1984; Karapetsas and Vlachos, 1997) and right, left, and mixed (Sanders, Wilson, and Vandenberg 1982; Snyder & Harris, 1993). In addition, mixed-handers have alternatively been omitted from studies or placed with one handedness group or the other (see Casey, 1996).

The use of left-handers and right-handers as distinct groups may be particularly problematic. Geschwind and Galaburda (1985 a,b,c) have suggested that left-handers are more likely to have atypical brain organization, which in some cases is advantageous to spatial ability, and in other cases is a detriment. Thus, left-handers would tend to be either end of the continuum of spatial ability--making overall comparisons of right vs. left handers difficult to interpret. It has also been suggested that it may be important to differentiate between subgroups of right-handers based on family handedness (Casey, Winner, Benbow, Hayes & DaSilva, 1993) and family handedness may be as important as individual handedness in predicting spatial abilities. For example, Taylor,

Naylor & Chechile (1999) found that sex interacted with family handedness to predict map reading and navigational ability.

In addition to a lack of consensus in how comparison groups are defined, there are differences in how handedness is actually determined. For example, handedness has been measured in different ways such as by questionnaires or looking at right vs. left hand skill performing timed motor tasks. How handedness is assessed is important to consider. It has been well established that assessment of hand preference cannot be based solely on writing, and mixed handedness does not mean that the individual would be ambidextrous for writing. Handedness Questionnaires, such as the Edinburgh Handedness Inventory (Oldfield, 1971) or the Revised Annett Handedness Inventory (Briggs & Nebes, 1975), have therefore been used to assess the direction and degree of handedness for a number of activities (for example, using a broom, opening a lid, and dealing cards). However, hand preference measures are not the only way of differentiating right, left, and mixed-handers. Annett (1985) has also found performance measures of relative hand skill such as finger tapping and peg-moving "to relate to handedness" (p. 227). For example, Annett and Manning (1990) found in studying peg-moving tasks that the strength of dextrality is associated with increased weakness in the left hand rather than increased in the right. The question remains: are these two methods interchangeable? A study by Verdino and Dingman (1998) suggests that while preference measures such as handedness inventories may be useful for assessing right- vs. left-handedness, proficiency measures may be needed to determine tendencies toward mixed-handedness.

Although some studies have shown a relationship between handedness and spatial ability, results in this area have been inconsistent. Among the problems in this line of inquiry has been a failure to account for sex differences in some studies, lack of consensus as to how handedness is assessed and defined, and the use of left-handers and right-handers as distinct groups. The work of Annett (1985) as expanded by Casey and her colleagues (Casey & Brabeck, 1989; 1990; Casey, Nuttall, & Pezaris, 1999; Casey, Winner, Benbow, Hayes, & DaSilva, 1993) has provided a theoretical basis for identifying subgroups of individuals based on both individual and family handedness. The following will consider genetic models of handedness, with particular emphasis on Annett's theory.

1.3.2 Genetic Models of Handedness

Theories attempting to link handedness directly to a particular gene have largely failed, but some researchers have proposed that handedness may be the result of genetic influences on lateralization for speech (Annett, 1985, 1999b, 2000; McManus, 1999). Attempts were made early in the twentieth century to understand handedness in terms of Mendelian genetics, with right-handedness being viewed as a dominant inherited trait, and left-handedness as recessive. However, such a model of handedness fails for at least two reasons. First, offspring of two left-handed parents are not always left-handed, as would be predicted by Mendelian theory. Second, if left-handedness were a randomly-occurring recessive trait, it would be expected to be expressed in 25% of the population, which is higher than the actual reported occurrence. Additionally, such a model of handedness fails to explain why there is a slightly higher incidence of left-handedness in men than women (Davis and Annett, 1994; Lezak, 1995) and twins than singletons (Coren, 1994; Davis and Annett, 1994).

The idea that handedness may be influenced by genetic (inherited) factors has been explored by a number of theorists (Annett, 1985, 2002; Crow, 2001; Klar, 1999; McManus, 1999; Yeo & Gangestad, 1993). Of the various theories attempting to explain how genetic factors may influence handedness, Annett's right-shift theory (1985, 2002) is among the most frequently cited. This is, perhaps, because her theory leads to a number of testable predictions regarding cognitive ability—particularly in women. In studying the relationship between handedness and lateralization for speech, Annett proposes that handedness in and of itself is not genetically determined (1985, 1999b, 2000, 2002). She theorizes, however, that what is inherited, a proposed right-shift gene, has an effect on the distribution of handedness. The proposed right-shift gene (rs+) is involved in the development of speech to be represented in the left hemisphere and increases strength and skill on the right side of the body in humans. It appears to have a slightly greater effect on females than males, thus possibly explaining both the tendencies for more men to be left-handed and female precocity for speech. Davis and Annett (1994), in work aimed at investigating this theory, have found evidence that the proposed rs+ gene may disadvantage the left hand (making the right hand advantage incidental). The rs+ gene may exert a greater effect on girls and single-born children than boys and twins due to factors involving the maturity of the affected language areas at birth.

The proposed rs+ factor can be inherited in single (rs+/rs-) or double (rs+/rs+) doses from parents or can be absent altogether (rs-/rs-). In describing her theory, Annett indicates that in approximately 20% of individuals are of the rs -/- genotype, and lateral asymmetries of hand and brain rely only on chance. When absent, the result is not left-handedness or right hemisphere speech, but

rather a lack of biasing to either side. The effect of such an absence of right-bias is a normal distribution of handedness (25%left, 25% right, 50% mixed) that fits with statistical analyses of handedness rates (Annett, 1985). Approximately 50 % of people are rs+/- and asymmetries are determined by chance (rs-) and a factor (rs+) which slightly handicaps the right hemisphere and weakens the left hand. The remaining 30% of people, the majority whom are right-handed, are rs+/+ and have a double handicapping factor to the right hemisphere. Pathological influences may impact this by giving additional handicaps to either side.

Since it is not possible to determine the presence or degree of the proposed rs+ factor directly, much of the work looking at the possible effects of the various supposed genotypes (rs+/+, rs+/-, and rs-/-) on cognition has been done by making assumptions based on individual and family handedness patterns. Right-handers with one or more left-handed or ambidextrous immediate biological relatives (RL) may be more likely heterozygotes then right-handers with all right-handed relatives (RR). Men and women have been found to differ in the expression of the rs+ gene, and are thus frequently studied as separate groups. It has been asserted that rs+/+ genotypes would have a handicapped right hemisphere, and that this would affect females more than males. The result of this may be a cost to spatial ability in women and, again, may be a factor in observed sex differences on spatial tasks.

It should be noted that an examination of cognitive ability in terms of Annett's right-shift theory is far from complete. Additionally, Annett's theory has not been free from criticism (Gangestad & Yeo, 1994; McManus, 1999; McManus, Shergill & Bryden, 1993; Yeo, Gangestad, Thoma, Shaw and Repa, 1997). Gangestad & Yeo have proposed that developmental instability is an

important determinant of handedness. Parents who are left-handed would be more likely to pass on a tendency for deviance from the norm, resulting in an increased likelihood that they would have either left-handed or extreme right-handed children. In other words, degree of deviation from typical handedness (slight bias to the right) is what would be inherited rather than the direction of handedness. However, their predictions primarily center on looking for markers of developmental instability (for example, wide-spaced eyes or slight body asymmetries) associated with deviant handedness. Their theory fails to predict or explain differences in spatial aptitude where right-handed women with left-handed relatives have a spatial advantage (Casey & Brabeck, 1989 &1990; D'Andrea, 1998; Weinstein, Kaplan, Casey & Horwitz, 1990) over right-handed women with all right-handed relatives.

McManus et al. (1993) have raised an objection to the notion that heterozygotes in the Annett model (rs+/-) have increased cognitive ability over homozygotes. In their own research they found no advantage on verbal or spatial measures for heterozygotes. They did not separate subjects by sex, however, which may be important since, according to Annett, the rs+ factor affects males and females differently. They state that in order to claim a "balanced polymorphism exists one needs to specify the costs incurred for both homozygotes" (p. 520). In response to this, Annett (1993, p. 541) offers the following:

> Whilst this is true, Rome was not built in a day. More than specifying the costs for each homozygote, my personal hope is that it will be possible to show some advantages for each homozygote also, so that there is a complex set of interacting advantages and disadvantages associated with all the genotypes, including the rs +/-...weakness presumably associated with the

> rs-/- genotype has been found for the very function expected... phonological processing...The hypothesis that the rs -/- have compensating strengths has been strongly supported by studies of spatial ability...It could be that the overall balance will be for human families, if different members have complementary strengths and weaknesses.

In addition, she indicates that if the rs+ gene is absent (rs--) then there is a greater chance of language difficulties (learning disabilities) whereas rs++ have a disadvantage spatially (1995). McManus' own theory, while sharing some similarities with Annett's in terms of the role of chance and a slight cerebral lateralization bias to the left, views handedness as a discrete rather than continuous variable. This distinction may be of particular importance when looking at relationships between lateralization/handedness and spatial ability. How handedness groups are classified can greatly influence results in this area. Significantly, studies (for example, McKeever, Seitz, Hoff, Marino & Diehl, 1983) which have failed to find spatial differences in right-handed based on family handedness in the expected direction have not defined family handedness groups in accordance with Annett's theory (for discussion of this problem, see Casey, 1996).

The problem of how the proposed genotype groups are defined may also pose difficulty in work looking at possible effects of such a handedness/lateralization gene. The work of Annett has focused primarily on differences in individuals grouped as to strength and direction of handedness, while the work of Casey and her colleagues has based groupings primarily on the presence or absence of familial sinistrality. However, these two methods of grouping individuals may not be interchangeable. D'Andrea (1998) found that right-handed women with left-handed relatives did not differ significantly from

women with all right-handed relatives in terms of strength of dextrality. While there was a relationship between family handedness and spatial ability in women, with RL women significantly outperforming RR women on a number of spatial performance measures, spatial performance differences were not found based on strength of right-handedness. Thus strong right-handers, as measured by the Edinburgh Handedness Inventory and measures of relative right- and left-hand skill (grooved pegboard and finger tapping tests) did not differ from weak right-handers in terms of spatial ability. Another possible problem with categorizing proposed genetic groups based on handedness differentials is that right- vs. left-hand ability may not be stable in women over time due to hormonal influences. For example, Saucier and Kimura (1998) found that differences between right- and left-hand accuracy was greater (favoring the right hand) in the midluteal phase of the menstrual cycle when estrogen is high. Given this, family handedness, while imperfect in its own right, may be a better predictor of group assignment in right-handed women than strength of dextrality. The following will examine work that has focused on a possible relationship between family handedness and spatial ability.

1.3.3 Family Handedness and Spatial Ability in Women

Casey and Brabeck (1989, 1990) have used Annett's theory as a basis for their own work. They postulate that rs+/+ individuals with a strong left-hemisphere bias would be dependent on verbal strategies for spatial tasks, but that men show less influence from this genotype based on slower maturation of the left hemisphere and language ability. They also consider the combined differences of genetic and environmental influences of strategies, indicating that girls choose more verbally-oriented strategies due to a combination of verbal

tendency and socialization factors. They cite activities generally considered "male," such as carpentry and building model airplanes, as increasing spatial ability. Thus, boys who are encouraged to participate in those activities would develop a further spatial advantage when compared to girls who are not. In sum, although, strong left hemisphere dominance in girls gives them a spatial disadvantage compared with boys, girls with non-right handed family members are more likely to have the optimal rs +/- genotype that helps girls spatially. This advantage, in turn, can be further enhanced by experiences.

One of the earlier studies done looking at spatial performance in women using groupings based on academic major as well as individual and family-handedness was conducted by Casey and Brabeck (1989). They found that on a mental rotation task, right-handed women in math and science fields with at least one left-handed or ambidextrous immediate relative outperformed other groups of women and did as well as men. The other groups of women included right-handed women with all right handed relatives and left-handed women who were also majoring in math and science. They explain these differences as being the result of genetic potential enhanced by experiences which may be selected as the result of that potential. Women who may have less ability spatially, but select math and science fields, may include those who effectively use non-spatially reliant (verbally-mediated) strategies to pursue their interest in these academic areas.

Pezaris and Casey (1991) found that girls who both most likely fit the optimal proposed genotype (RL) and had spatial experiences (as indicated by high math and science achievement) used more visual-spatial strategies and

fewer verbal strategies than the girls in the other groups. Overall, girls other than those in the targeted group preferred verbal strategies.

Using Annett's genetic theory combined with environmental factors, Weinstein, Kaplan, Casey & Hurwitz (1990) looked at female college student performance using the Rey-Osterrieth figure. Low performers on organization measures were those women with low math/science background and all family right-handers. These women tended to be part-oriented (left hemisphere strategy reliant). High scorers were high math/science right-handed women who either had left-handed immediate relatives or who showed mixed-handed tendencies. These women tended to use a more configurational, right-hemisphere strategy. This agrees with Bennett-Levy's (1984) findings in which high scorers on spatial aptitude tend to use a more holistic approach on the Rey-Osterrieth figure.

However, experiential factors may not account for many of the within-sex differences in women. As mentioned earlier, work by D'Andrea (1998) found that academic major did not significantly contribute to differences between women, but family handedness did. Recent work by Casey, Nuttall & Pezaris (1999) also supports the notion that genetics may influence ability to capitalize on experiential factors. They found that 8th grade girls in both the proposed rs+/- and rs+/+ groups sought out spatial experiences equally. However, rs +/- girls benefited more from this experience, as assessed by mental rotation performance than the other girls.

In sum, a number of studies have examined whether or not there is a direct relationship between handedness and spatial ability, with inconsistent results. Problems in this line of results have included how handedness is defined

and assessed. In addition, sex and family handedness may also influence any relationship between handedness and spatial ability.

Although existing genetic theories of handedness continue to be controversial, Annett's right-shift theory, in which handedness results from genetic influences on left-hemisphere dominance for speech, makes testable predictions about cognitive ability that have been examined. Individuals have been assigned to proposed genotypes for study based on handedness/family handedness patterns or by performance differences between right- and left-hand skill. However, it is important to note these two methods may not be interchangeable.

Work looking at female cognitive ability in terms of the right-shift theory has shown that women with the strongest bias to the left hemisphere (rs+/+) may have a spatial disadvantage as well as a corresponding reliance on verbal strategy. Women with the proposed rs -/+ genotype, on the other hand, may perform as well as men on spatial measures and better utilize spatial strategies. In terms of the right-shift theory, overall male spatial superiority may be the result of a lesser effect of the rs+ gene on males than females. Few studies have been conducted looking at males in terms of family handedness, but a convincing effect of the proposed rs+ gene has not been established in men (Casey & Brabeck, 1989; McKeever, 1986). Thus, the right-hemisphere of males may be less impacted by the proposed rs+ gene than that of females. The following section will consider another factor that may influence both cognitive sex differences and lateralization—gonadal hormones.

1.4 Hormones

The previous sections have described how sex and possible genetic factors related to handedness and family handedness may impact individual differences in spatial abilities. This section will examine work considering the role of gonadal hormones in cognitive functioning and how hormones may contribute to cognitive sex differences.

The roots to understanding the effects of hormones on cognitive performance come out of basic science research. This research has indicated that hormones influence the brain in a number of ways involving both genetic and non-genetic mechanisms (McEwen, 1994). Work has shown that gonadal hormones may exert their effects by influencing the formation of neuronal connections, impacting neurotransmitter systems, and by serving a protective function in the brain.

There is evidence that both estrogens and androgens are able to act as "neural growth factors in cells that express the appropriate receptor, leading to stereotyped changes in neural growth and pattern formation" (Lustig, 1996 p. 376), with testosterone promoting axonal development and estrogen dendritic development. Estrogen promotes communication between neurons containing estrogen receptors by increasing spines and gap junctions, thereby increasing the likelihood of contact. Androgens increase the target area of neurons, making the chances of interneural communication greater. The form of estrogen used in estrogen replacement therapy (conjugated equine estrogen) has been shown to increase neuronal morphology in hippocampal, basal forebrain, occipital, parietal, and frontal cortex in rat neurons (Brinton et al., 2000). Gonadal steroids have been shown to regulate the number of spines in the CAI region of the

hippocampus in female rats (Gould et al., 1990). Dendrites in neurons in the ventromedial hypothalamus and the CA1 region of the hippocampus show changes in spine numbers over the course of the rat estrous cycle (McEwen & Woolley, 1994) with an increase in spine density associated with increased estradiol levels and a decrease associated with decline in estradiol and increase in progesterone. There is evidence that progesterone speeds up the decline in loss of spines and synapses in the hippocampus that occurs with loss of estrogen (McEwen & Woolley, 1994). Other work has shown increased estrogen when paired with increased progesterone, leads to increased synaptic density in the CA1 region of the hippocampus but less than estrogen alone (Silva, Mello, Freymuller, Haidar, & Baracat, 2000).

The change in the number of synapses following changes in estrogen levels is significant (Woolley et al., 1990) and can occur rapidly. One possible mechanism for estrogen's action is that it may affect brain-derived neurotrophic factor (BDNF mRNA) in the hippocampus. BDNF has an important role in synaptic plasticity in hippocampus and neural connectivity. (Gibbs, 1999). Estrogen may also exert an influence through the cholinergic system that is involved in learning and memory. Cholinergic effects are particularly interesting with regard to the proposed study in that they have been shown to play a role in spatial strategies (Janis, Glasier, Fulop, & Stein, 1998). Estrogen receptors have been found in cholinergic neurons--supporting the notion that estrogen may influence these neurons to affect cognitive functioning (Shughrue, Scrimo & Merchenthaler, 2000; Toran-Allerand et al., 1992).

The beneficial effect of estrogen on the function of projections to the hippocampus and cortex has been a possible mechanism for protecting the brain

from adverse effects of cholinergic functional decline that can occur with aging and, in particular, with Alzheimer's disease (Gibbs & Aggarwal, 1998; Gibbs, Burke & Johnson, 1998). Estrogen replacement has been shown to affect choline acetyltransferase and nerve growth factor receptors--both of which play a role in cholinergic function in the hippocampus--and there is evidence that this role may be related to learning and memory. (Gibbs, 1994).

Estrogen may also impact other neurotransmitter systems. Estrogen may increase 5-HT receptors and serotonin transport in areas of the brain involved with mood, memory and cognition and neuroendocrine control (Fink, Sumner, McQueen, Wilson, and Rosie, 1998). Estrogen may increase dopamine release in basal ganglia leading to improvement in sensorimotor performance (Becker & Beer, 1986). Dopamine modulated transmission in temporal prefrontal loop may also be regulated by estrogen and progesterone (Saigusa, Takada, Baker, Kumar, & Stephenson, 1997)

Finally, estrogen may serve a protective function against some neurotoxins (Honda et al., 2000) associated with Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis (ALS). The pathways (tyrosine kinase/MAPK pathways) activated by estrogen may have both a cognitive effect by enhancing NMDA receptor function and by enhancing long-term potentiation (cellular model for learning and memory) as well as a neuroprotective effect (Bi, Broutman, Foy, Thompson, & Baudry, 2000). There has been some suggestion that estrogen replacement may help improve cognitive function in women with multiple sclerosis (Sandyk, 1996), may serve a protective function against permanent brain damage following stroke (Dubal et al., 1998), and protect

against some toxic agents which have been associated with Alzheimer's disease (Brinton et al., 2000).

In sum, research has shown that estrogens and androgens influence neuronal growth, with testosterone promoting axonal development and estrogen dendritic development. Changes in estrogen levels can rapidly produce significant changes in the number of synapses. Possible mechanisms for estrogen's action include impacting neurotransmitter systems (e.g.: serotonin and dopamine), affecting brain-derived neurotrophic factor (BDNF mRNA) in the hippocampus, and by influencing the cholinergic system that is involved in learning, memory and, perhaps, spatial strategies. The following will examine more closely how hormones lead to both permanent and temporary changes in the brain.

1.4.1 Organizing and Activating Effects of Hormones

Hormones are involved in both permanent (organizing effects) and temporary changes (activating effects) in the brain at both the chemical and structural levels (McEwen, 1991). Interestingly, there is evidence that hormones impact cognitive performance through mechanisms involving both of these types of effects. Permanent organizing effects of hormones occur during sensitive periods of development early in gestation, just after birth, and during adolescence and lead to sexual dimorphism (Cherrier, 1999). For example, during critical periods prior to birth and just after birth, testosterone, which has been converted to a form of estrogen, de-feminizes the brain by influencing cell migration, cell survival and death, and neural plasticity (Beyer, 1999; Breedlove, 1992).

Since gonadal hormones have been shown to affect brain organization and structure in ways that are sex-specific (Beyer, 1999; Swerdloff, Wang, Hines, and Gorski, 1992), neuroanatomical differences that exist between men and women may be largely influenced by hormonal levels which exert an impact on neuronal survival and morphogenesis leading to CNS structure differences (Arnold & Gorski, 1984) between the sexes. For example, at 13 weeks gestation the right cortex in females and the left prefrontal cortex in males is more developed in relation to other brain areas (De Lacoste and Howath, 1985) and these differences correspond with peak secretions of testicular androgen. Increasingly, work has looked at how differences in tissue composition particularly in the parietal lobe (Nopoulos, Flaum, O'Leary, and Andreasen, 2000; Reiss et al., 1995), may be related to genetic influences on hormone levels prenatally.

In addition to structural differences, sex differences in cognitive abilities are thought to be influenced by hormones during development (Sherwin, 1994). Cognitive differences between males and females may be at least partially due to organizing effects that result in anatomical differences in a number of areas involved in spatial ability including the parietal lobe and hippocampus. For example, testosterone given to rats just after birth has caused the female rat hippocampus to appear like that of a male rat and improved spatial ability (Roof & Havens, 1992). The female rat hippocampus may be "masculinized" by testosterone elevations during critical periods, leading to structural differences that may, in turn, affect navigational strategy differences in males and females (McEwen, Gould, Orchinik, Weiland, and Woolley, 1995.)

In humans, CAH patients have high adrenal androgen production due to high adrenocorticotrophic hormone levels. These high levels of adrenal

androgens occur prenatally and postnatally until treatment. Women with CAH have been found to have higher spatial ability and lower verbal ability compared with their siblings**.** DES (synthetic estrogen) given to pregnant women has also been shown to have a masculinizing/defeminizing effect on females offspring. These girls have a more masculine pattern of performance (reviewed in Sherwin, 1994). Interestingly, males exposed to DES in utero had reduced lateralization and lower spatial ability than their unexposed male siblings (Reinisch & Sanders, 1992). Another study (Wilcox, Maxey and Herbst, 1992) failed to find generalized intellectual effects based on achievement testing of young adults who had been exposed to DES in utero. This is important in that sex difference research has also found differences occur not in overall intelligence, but in specialized functioning such as spatial ability. West African males suffering from kwashiorkor in infancy have also been studied. Kwashiorkor damages the liver, which can no longer inactivate estrogen, leading to increased estrogen and "feminization" including lower spatial and higher verbal skills compared with control males (Binnie-Dawson & Cheung, 1982).

Findings that later maturing girls may have a spatial advantage (Meurling, Tonning-Olsson, and Levander, 2000) over girls who mature earlier lends support to the notion that hormonal levels may continue to exert permanent effects during adolescence. More recently, it has been found that changes in hormone levels have significant anatomical and behavioral effects not just during development, but in adulthood as well (DeVoogd, 1994). Hormones program cells of males and females to differ in how the brain responds to hormones (McEwen, 1994). There is some suggestion that levels of hormones in the adult is correlated with individual levels prenatally (Mikle, Stringham,

Bishop, & West, 1988) perhaps giving some window into the more permanent organizing effects of these hormones on abilities.

Activating or modulating effects are reversible and occur with alterations in hormone levels such as fluctuations that occur seasonally, monthly (menstrual cycle), during pregnancy (Frankfurt, 1994) or changes that occur over the lifespan (e.g., aging and/or menopause). Activational effects of gonadal steroids not only impact reproductive behaviors, but also likely influence cognitive performance in areas such as learning, memory and visuospatial skills. Activating effects make it possible for hormones not only to contribute to differences between individuals, but also to fluctuations in ability within an individual during different periods in time.

Two gonadal hormones in particular, estrogen and testosterone, have been implicated in spatial abilities. In a study by Hausmann, Slabbekoorn, Van Goozen, Cogen-Kettenis and Gunturkun (2000) a number of hormones were measured (estradiol, progesterone, testosterone, luteinizing hormone, and follicle-stimulating hormone) in women (aged 23-38 years) every three days for six weeks. Mental rotation performance was significantly higher during the menstrual phase. This study found two hormones were related to mental rotation ability, with high testosterone and low estrogen mostconducive to mental rotation performance. Progesterone and LH and FSH were not found to be related to mental rotation ability. The following will look at the work separately considering the role of estrogen and testosterone in cognitive performance.

1.4.2 Estrogen

There is considerable support for the notion that estrogen plays a significant role in regulating affect and memory (Sherwin, 1996) and may contribute to sex-based differences in cognitive patterns as well as vulnerability to certain psychiatric disorders (Halbreich, Lemus, Lieberman, Parry, and Schiavi, 1990). Estradiol exerts its effect very quickly by directly impacting the excitability of neurons in the cerebral cortex, hippocampus and cerebellum (McEwen, 1994). Estradiol has been shown to enhance spatial memory in rats (Luine, 1994), although studies in humans have generally indicated that estrogen helps with verbal memory but has either no effect or a negative effect on visuospatial memory (Sherwin, 1994).

Research looking at the relationship between hormone levels and cognitive functioning in humans has primarily focused on cognitive changes associated with hormone decreases in aging, the impact of hormone replacement therapy (ERT) and hormonal fluctuations over the menstrual cycle.
Studies looking at the possibility that cognitive abilities might be preserved or even improve after estrogen replacement have yielded mixed results (Newman, 1999; Placios, Cifuentes, Menendez, & von Helde, 2000; Wang et al., 2000; Yaffe, Sawaya, Lieberburg, & Grady, 1998). Sherwin (1998) has argued that estrogen replacement may meaningfully protect or improve verbal and memory function in elderly women (Sherwin, 1998). Some work has found verbal fluency to be better with estrogen replacement (Grodstein et al., 2000). Carlson & Sherwin (1998 & 2000) found menopausal women using estrogen to have better digit span forward and backward, which places a demand on verbal working memory, attention and concentration. These same researchers, however, did not find

differences on a number of other verbal memory measures such as paired associate learning or paragraph recall. A study by Phillips and Sherwin (1992a) found that the positive effect of estrogen appeared to be specific for verbal tasks, not visuo-spatial memory, although some studies have seen benefit in visuospatial memory tasks (Resnick, Maki, Golski, Kraut, & Zonderman, 1998; Sherwin, 1998) and even a general cognitive benefit to ERT (Kimura, 1995; Verghese et al., 2000).

Phillips & Sherwin (1992a) looked at the effect of estrogen given to women following hysterectomy. They found that estrogen treated women did not have a decline in memory function on paired associate learning, but women given a placebo did. Some work has found, however, that estrogen did not serve a protective function against cognitive decline in older adults (Barrett-Connor & Kritz-Silverstein, 1999; Resnick et al., 1998; Yaffe, Grady, Pressman, & Cummings, 1998).

Why have results been inconsistent? A number of reasons are possible, including task selection, individual differences, and how estrogen treatment is administered. Individual differences may influence how estrogen impacts the central nervous system, perhaps due to previous organizing effects (Miranda, Williams, and Einstein, 1999). There has been some suggestion that genetic factors may play a role in whether or not particular women benefit cognitively from estrogen replacement treatment (Yaffe, Haan, Byers, Tangen, & Kuller, 2000). Other Individual differences such as estrogen exposure history (age of menarche and menopause and number and length and timing of pregnancies) may also play a role in estrogen sensitivity (Smith et al., 1999). Estrogen replacement results may also be influenced by how estrogen is administered.

For example, the fact that long-term treatment may not be effective may be because the cells may require cyclical exposure to hormones for benefit to occur (Miranda et al., 1999). Also Estrogen-progestin used together may have some negative effects on cognition (Rice et al., 2000) although this combination has been shown to be beneficial for spatial tasks in animal studies (Gibbs, 2000). Another problem with ERT research is weather or not actual levels are assessed (Wolf et al., 1999). For example, Drake et al., (2000) found high estradiol levels in healthy elderly associated with verbal memory and low levels with visual memory.

Menstrual cycle studies have also been done to look at the impact of shorter-term changes in hormone levels. Emotional changes over the course of the menstrual cycle have been well documented, and some have argued that changes over the menstrual cycle related to mood and response to emotional stimuli may have reproductive significance (Wang & Johnston, 1993). Although emotional changes may impact aspects of cognitive function, increasing evidence points to the idea that cognitive changes may occur during the course of the menstrual cycle that are unrelated to and cannot be accounted for by mood changes (Man, MacMillan, Scott, and Young, 1999).

Research studies considering cognitive performance within women over the course of the menstrual cycle have generally found a positive correlation between performance and estrogen levels for tasks at which women typically outperform men. For example, fine manual speed performance (Hampson & Kimura, 1988; Hampson, 1990a; Jennings, Janowsky, & Orwoll, 1998; Szekely, Hampson, Carey, & Goodale, 1998), and verbal skills (Hampson, 1990b) were greater during times of increased estrogen during the menstrual cycle. Estrogen

elevations may also have an enhancing effect on verbal memory (Sherwin, 1994) and possibly spatial memory (Postma, Winkel, Tuiten, & Honk, 1999). Work looking at a possible relationship between fluctuating hormonal levels over the course of the menstrual cycle and memory (Phillips and Sherwin, 1992b) have found that decreases in estrogen and progesterone during the menstrual phase corresponded with lower visual memory scores. Low estrogen levels resulting from drugs used in preparation for in vitro fertilization have also been associated with cognitive difficulties in memory and fine motor skills. (Varney, et al., 1993)

While increased estrogen may enhance verbal and memory performance, decreased estrogen and progesterone are associated with improving functions that typically favor males. For example, women perform better during the menstrual phase (when estrogen and progesterone are relatively low) on sensorimotor inhibition (Swerdlow, Hartman, & Auerbach, 1997) and the performance of some spatial (Broverman et al., 1981; Hampson & Kimura, 1988; Hampson, 1990a) and abstract reasoning (Hampson, 1990b) tasks. Interestingly, improvement of mental rotation task scores when estrogen levels were low has been demonstrated in psychotic women (Thompson, Sergejew, & Kulkarni, 2000).

Not all researchers have found performance differences across the menstrual cycle. Gordon & Lee (1993) did not find significant cognitive differences associated with changes in hormonal levels, although they used composite measures. This is problematic in that most studies have found significant effects only on specific types of spatial, verbal, and/or motor tasks. A study by Chiarello, McMahon and Schaefer (1989) found women did better on Judgment of Line Orientation at a time in the cycle when estrogen should be at a

peak, which is the opposite of what would be expected. However, it should be noted that these researchers did not measure hormone levels directly. Another study by Janowsky, Chavez, Zamboni and Orwoll (1998) looked at spatial performance using Block Design. As expected, men outperformed women on Block Design. However, contrary to prediction, women did best on Block Design when estrogen levels were high. Interestingly, there was no corresponding improvement on a mental rotation task. Although it is uncertain why this pattern of results occurred, these researchers suggest one possibility is that men and women may use different strategies to solve Block Design problems. If women prefer a part-oriented (verbal) strategy and can successfully apply it to Block Design problems, then optimal performance may actually occur at times when estrogen is elevated due to possible estrogenic enhancement of verbal performance.

Thus, how individuals solve tasks may be an important factor to consider when looking at the relationship between hormone levels and performance. If a spatial task can be successfully completed using "verbal" analytic strategies, then estrogen may have an enhancing effect that is not found for tasks that necessitate the use of "spatial" strategies. Additionally, it is possible that changes in estrogen/progesterone levels are reliably associated with performance differences only for the most difficult tasks that reliably differentiate between women and men such as mental rotation. There may be an optimal range of estrogen for different skills --one level for some skills and another for other skills-- perhaps related to behaviors associated with fertility and reproduction (Desmond and Levy, 1997) or maternal behaviors. (Woolley, 1998). Interestingly, Phillips and Sherwin (1992b) found that not all women appeared to be

cognitively affected by the same fluctuations in hormones. In their study, about half of the women showed a decline in visual memory during the menstrual phases. These women could not be differentiated from other women based on absolute levels of sex hormones measured (estradiol, progesterone, and free testosterone), and did not show differences from the other women in terms of mood. Thus, factors other than absolute hormone levels and mood impacted performance. Interestingly, absolute hormone levels also cannot distinguish between women with PMS and without (Rubinow, Schmidt, and Roca, 1998). Other researchers (Slabbekoorn et al. 1999) have favored the notion that some factor may influence susceptibility to hormone changes. One possibility is that differences in spatial problem solving strategy may impact the way estrogen levels affect spatial performance.

Given that men are not expected to show significant fluctuations in estrogen, few studies have been conducted looking at estrogen levels in men. However, findings have suggested a positive relationship between naturally occurring estrogen and visual memory in men (Kampen & Sherwin, 1996). In male to female transsexuals, those treated with estrogen have been shown to have an advantage on some tasks that favor women (associate learning) over those who have not (Miles, Green, Sanders, & Hines, 1998).

There is significant evidence that estrogen plays a role in cognitive performance. On the one hand, relatively high levels of normally-occurring estrogen have generally been associated with enhanced performance on those tasks that typically favor women (e.g., fine motor and some verbal and memory tasks). On the other hand, lower levels are associated with increased performance on some spatial tasks that typically favor males. However, it has

been suggested that there are individual differences in how women's spatial performance is impacted by estradiol fluctuations over the menstrual cycle. One possible explanation for this may be related to individual differences in spatial aptitude and/or strategy use.

1.4.3 Testosterone

Testosterone levels may impact cognitive performance patterns in men and women, and may also influence lateralization and handedness. Testosterone has been shown to affect several areas of the brain including the frontal cortex, amygdala, and hippocampus. Animal studies provide evidence that testosterone given prenatally can make the female rat hippocampus resemble that of males, and the administration of testosterone can improve spatial memory performance in both male and female rats.

As mentioned earlier, children with congenital adrenal hyperplasia, which involves androgen elevations in utero beginning in the third fetal month have been studied. While it has been found that girls with CAH have higher spatial scores than female controls, CAH has been associated with decreased spatial ability in affected boys (Hampson, Rovet, & Altmann, 1998). Another study (Kelso, Nicholls, Warne, and Zacharin, 2000) found androgen elevations due to CAH may not only correlate with higher spatial ability in girls, but also may impact handedness—causing a shift away from strong right-handedness.

Other work looking at a relationship between androgen and handedness has considered the impact of seasonal changes in testosterone. Females have been found to have seasonal variations in testosterone levels, with lower testosterone in spring than fall. In addition, both men and women have demonstrated more left-hemisphere dominance in spring than fall (Wisniewski

and Nelson, 2000), although males did not differ in testosterone levels in this study. Given these findings as well as other work looking at a relationship between handedness and testosterone, Nicholls (1998) looked at whether or not increased maternal testosterone levels in the first trimester (associated with seasonal variation) ma impact handedness in female offspring. Females born in spring months were found to have an increased incidence of left-handedness, presumably due to their mothers' higher testosterone levels in the fall. A similar pattern has not been shown in male offspring, possibly due to already higher androgen exposure in utero.

Hand preference may moderate the relationship between testosterone and spatial ability. For example, Moffat and Hampson (1996a; 1996b) found that testosterone may play a role in hand preference with left-handers having lower testosterone levels that right-handers. Cognitively, optimal level of androgens for spatial ability may fall between the average level for men and the average of women (Kimura, 1987). Work done by Gouchie and Kimura (1991) suggests that men with lower testosterone levels did better on tasks that are traditionally male such as spatial and mathematical reasoning. However, women with higher levels did best on these tasks. This suggests that a moderate level of testosterone is optimal for these tasks in which men tend to excel, a finding that has been found for other researchers looking at spatial functioning (Barrett-Connor, Goodman-Gruen, and Patay, 1999; Shute, Pellegrino, Hubert, & Reynolds, 1983). This pattern of normal men with relatively lower testosterone levels outperforming women and other men on mental rotation (Neave, Menaged, & Weightman, 1999) suggests that the relationship between testosterone levels and spatial ability is curvilinear such that there is an optimal level of testosterone for

spatial ability. O'Connor, Archer, Hair and Wu found increasing testosterone in eugonadal men inhibited spatial abilities and improved verbal fluency, supporting both the ideas of a non-linear relationship between testosterone levels and spatial performance and that optimal hormone levels are different for different cognitive abilities. One possibility for increased verbal performance may be that increasing testosterone levels increased estrogen.

Some researchers argue that this optimal level may vary as a function of task difficulty. For example, Silverman, Kastuk, Choi & Phillips (1999) found that higher levels of testosterone were beneficial to more difficult spatial tasks, but detrimental to easier tasks. Differences in testosterone levels have been linked to differences in cognitive patterns in homosexual vs. heterosexual men (Neave, Menaged, & Weightman, 1999) as well as in alcoholics (Errico, Parsons, Kling, and King, 1992). Older men, who have shown a decrease in testosterone below optimal levels may also improve spatial memory with testosterone replacement (Cherrier, 1999; Swerdloff & Wang, 1993a,b) which may act by a suppressive effect of estrogen (Janowsky, Oviatt, & Orwoll, 1994). Sex differences on spatial tasks have been shown to disappear after women have been treated with testosterone (female to male transsexuals) (Slabbekoorn, vanGoozen, Megens, Gooren, & Cohen-Kettenis, 1999). Although testosterone, at least in moderate doses may enhance female performance for tasks at which men tend to excel, some work indicates there may be some detrimental effect on tasks, such as verbal fluency, in which women excel (Wolf et al., 2000).

In sum, basic science research that has shown that hormones influence the brain in a number of ways. Work has indicated that gonadal hormones may influence neuronal connections, impact neurotransmitter systems, and serve a

protective function in the brain. Hormones are involved in both permanent (organizing effects) and temporary changes (activating effects) in the brain at both the chemical and structural levels (McEwen, 1991). Two gonadal hormones in particular, estrogen and testosterone, have been implicated in spatial abilities. For women, optimal performance on spatial measures has been associated with relatively low levels of estrogen. However, this may not be the case for all spatial tasks, particularly those that lend themselves to verbally-based problem solving strategies. Higher spatial task performance has also been associated with relatively high testosterone levels in women. However, men with relatively low levels of testosterone have been the top spatial performers in a number of studies.

1.5 Summary and Conclusions

Cognitive sex differences are well established in the literature, with men generally outperforming women on spatial tasks and women outperforming men on some verbal ones (Maccoby & Jacklin, 1974). The largest and most consistent sex differences have been found on spatial tasks, particularly those involving spatial orientation, spatial visualization, and spatial perception (Kimura, 1999). A number of possible explanations for these findings continue to be explored including sex differences in socialization, brain organization, maturation rates, hormonal levels, and/or the use of particular problem-solving strategies.

On average, men and women may differ in both their preference for and facility in using "right-hemisphere/spatial" versus "left-hemisphere/

verbal"problem-solving strategies. Typically, men more often utilize spatial or gestalt-oriented strategies, while women rely more on verbal or feature-based strategies to solve spatial problems. Which of these approaches is most advantageous to performance may depend on the demands of the particular task at hand. Individuals who are generally most adept at using spatially-oriented strategies have been shown to perform better on some visuospatial tasks—particularly those that favor males. However, much remains to be learned about the role of strategy across a variety of spatial tasks and how best to assess it. In addition, the extent that specific spatial tasks are able to be successfully solved using verbally-oriented versus spatially-oriented strategies needs to be further explored.

While many researchers cite strategy differences between the sexes as a possible explanation for their findings, this is often not assessed directly. For example, work has been done looking at the cognitive effects of estradiol fluctuations during the menstrual cycle. Much of this research has found that cognitive performance changes parallel sex-based cognitive patterns, with high estradiol associated with relatively greater verbal performance and low estrogen associated with enhanced spatial performance. Researchers who have had to explain results inconsistent with these patterns have theorized that task factors, particularly involving differences in problem solving strategy, may help explain their findings. For example, if a spatial task can be solved using a preferred verbal strategy, optimal performance would occur when verbal, not spatial, performance is at its peak. However, no known studies have actually assessed strategy use directly in order to test these assertions. Furthermore, not all women rely on verbal strategies to solve spatial problems. It is not known if

estrogen levels impact cognitive performance differently for those women who are adept at spatial strategies versus those who are not.

Within-sex cognitive differences have been studied by looking at how lateralization/handedness may impact spatial performance. Studies exploring a possible relationship between handedness and spatial ability have yielded inconsistent results. Problems in this line of inquiry have included inconsistent ways of defining handedness groups and determining handedness, failure to account for sex differences in some studies, and difficulties in task selection. Also, how handedness itself is conceptualized has differed, for example is handedness a discrete or a continuous variable?

Annett (1985) is among those theorists who argue handedness is a continuous variable. Her right-shift theory asserts that degree, not direction, of handedness may be the best predictor of spatial ability, at least in right-handed women. According to Annett, a genetic right-shift (rs) factor induces left-hemisphere speech by exerting a handicapping effect to the right hemisphere. If the rs factor is inherited from both parents (rs+/+), the effect would be strong dextrality due to a relatively large handicap to the right hemisphere and a resultant cost to spatial ability. If inherited only from one parent (rs+/-), the typical result would be right-handedness with strong sinistral tendencies and no spatial disadvantage. Although some studies have included left-handed women, under the right-shift theory, most left- handed women do not inherit the right-shift factor. Those with the rs -/- genotype lack the biasing factor that leads to right-sided speech and cerebral organization is determined by random factors. "Due to this variability in their brain organization, no predictions can be made about the spatial abilities of non-right handers...However, differences can be

predicted between those right-handed individuals carrying the heterozygous (rs +/-) and the homozygous (rs +/+) right-shift factor." (Casey and Brabeck, 1990, p. 75.) For this reason, combined with evidence that left-handed women are not top visual-spatial performers, interest in cognitive differences in women based on the right-shift theory has become focused on subgroups of right-handed women.

A number of studies have examined some of Annett's predictions surrounding the proposed rs factor and spatial ability in right-handed women. Rather than base group membership (rs+/+ versus rs+/-) on strength of dextrality measures (e.g. handedness inventories) or motor performance measures (e.g. right minus left hand skill), as Annett has done, other researchers (Casey & Brabeck, 1989; Casey, Nuttall & Pezaris, 1999; D'Andrea, 1998; Weinstein, Kaplan, Casey & Hurwitz, 1990) have made assumptions about proposed genotype assignment based on family handedness. Thus, right-handed individuals with all right-handed immediate biological relatives (FS-) would be likely to be rs+/+ and those with one or more left-handed relatives (FS+) would be considered to be rs+/-. Casey and colleagues have found that family handedness along with environmental factors (exposure to spatial experiences), when paired, have predictive value for spatial ability in right-handed women. However, D'Andrea (1998) found that while family handedness predicted spatial ability and strategy use in right-handed women, environmental factors did not.

Although several studies have shown that FS+ women have a spatial advantage over FS- women, a number of problems exist. As mentioned, Annett has relied on strength of dextrality and performance measures to determine

group membership while other studies have used family handedness. However, these two methods may not be interchangeable. For example, D'Andrea (1998) found that while FS+ women significantly outperformed FS- women on spatial performance and organization measures, FS- and FS+ women did not show differences in dextrality based on handedness questionnaires or performance measures (absolute and right- minus left-hand skill for finger tapping and grooved pegboard). Thus, if FS- women are supposed to be of the rs+/+ genotype, they did not demonstrate the strong right-handedness predicted by Annett. Furthermore, strongly right-handed women did not perform significantly differently from those with more mixed tendencies. Another problem with groupings based on performance measures is that right- minus left-hand differentials may change over the course of the menstrual cycle. Given this, family handedness, while imperfect in its own right, may be a better predictor of group assignment in right-handed women than strength of dextrality.

According to Annett, overall male spatial superiority may be the result of a lesser effect of the rs+ gene on males than females. Few studies have been conducted looking at males in terms of family handedness, but a convincing effect of the proposed rs+ gene has not been established in men (Casey & Brabeck, 1989; McKeever, 1986). One possibility offered for this is that the right-hemisphere of males may be less handicapped by the proposed rs+ gene than that of females. Despite findings that family handedness can predict spatial ability in right-handed women, it is uncertain whether it works in the way Annett describes. First, it is unknown if such a gene exists and using family handedness to predict genotype is highly imperfect. In addition, other

researchers have proposed alternatives such as genetic influences on handedness may be x-linked and/or handedness and spatial ability may be linked to testosterone levels. Relatively high maternal testosterone levels have been associated with increased spatial ability and increased left-handedness in female but not male offspring. In adults, there is evidence that increased spatial ability is associated with relatively low estrogen and relatively high testosterone levels in women and relatively low testosterone in men. Again, however, this may not be the case for all spatial tasks, particularly those that lend themselves to verbally-based problem solving strategies.

2. Statement of the Problem and Hypotheses

The primary aim of this study was to examine a number of factors that may contribute to visuospatial ability in healthy young adults. These include sex, family handedness, circulating gonadal hormone levels (estradiol and testosterone), and problem solving strategy. Although the role of each of these factors was considered independently, the primary focus of this study was to explore possible interactions between these factors. Of particular concern was whether or not strategy preference and spatial aptitude might influence the way normal fluctuations in estradiol impact cognitive performance over the course of the menstrual cycle. This was planned to be done in one or both of two ways: (1) It is suggested that FS+ women have a genetic predisposition to high visuospatial organization ability and will outperform FS- women on spatial tasks. Thus, FS- and FS+ was used as a way of grouping high spatial aptitude/strategy vs. low spatial aptitude/strategy women. (2) Because the first grouping method assumes significant differences would be found between FS- and FS+ women, direct comparison of women based on strategy and performance measures was planned, provided evidence was found that the women had a preferred strategy across tasks.

A second goal of this study was to examine aspects of Annett's theory and the work of Casey and colleagues that have not been given adequate attention. The first of these aspects involves the question as to whether family handedness or strength of dextrality better predicts spatial performance. Previous work (D'Andrea, 1998) has found these two grouping factors may not be interchangeable, raising interesting questions regarding Annett's theory.

Second, this study compared FS- and FS+ men as well as women on a number of spatial tasks. Finally, the possibility of a relationship between testosterone and family handedness was explored.

This study looked at right-handed young adults grouped as to family handedness (all right-handed relatives (FS-) or at least one left-handed relative (FS+)) and sex (male or female). Women were tested twice at times corresponding to the late follicular and menstrual phases of their cycle. Men were also tested twice at a similar interval. Based on the literature and previous work in this area, the predictions listed on the following page were made:

Hypotheses

Expected main effects for sex

1. A main effect was expected for sex on spatial measures, with men outperforming women. It was expected that, as a group, men would use more holistic/spatial strategies, and women would rely more on part-oriented/verbal strategies to solve spatial problems.

2. A main effect for sex was expected on motor tasks, with men outperforming women on finger tapping, and women outperforming men on grooved pegboard.

Sex x family handedness interactions

3. FS+ women were expected to outperform FS- women on spatial measures. It was also predicted that FS+ women would utilize more holistic/spatial strategies and FS- women would rely more on part-oriented/verbal strategies to solve spatial problems.

Main effects for menstrual cycle phase

4. Women were expected to show improved performance on spatial measures during the menstrual phase as compared with the late follicular phase.

5. Women were expected to show decreased fine motor task performance (Grooved Pegboard) during the menstrual phase as compared with the late follicular phase.

Family handedness x menstrual cycle phase interactions

6. A family handedness x test phase interaction was predicted, with FS+ women expected to show greater enhancement of spatial performance during the menstrual phase than FS- women.

Sex x spatial strategy x test phase

7. Provided strategy type was consistent across tests, women who used spatial/holistic strategies were expected to show a greater enhancement of spatial performance during the menstrual phase than those who used verbal/analytic (part-oriented) strategies.

Testosterone

8. Women with relatively high free testosterone levels were expected to perform better on spatial tasks than women with relatively low testosterone levels.

9. Men with relatively low testosterone levels were expected to perform better on spatial tasks than men with relatively high testosterone levels.

3. Method
3.1 Participants

The participants for this study consisted of 50 right-handed young adult volunteers (24 male/26 female), ranging in age from 18 to 34 years (x= 20.74 years, sd = 3.06). Of the 50 volunteers, 74% described themselves as Caucasian, 14% Asian, 8% African-American, and 4% Latino. Participants were primarily Drexel University undergraduates from a variety of academic majors (see Figure 1) with years of education ranging from 12-19 (x=13.91 years, sd=1.52). All of the participants were recruited either through psychology classes at Drexel or an advertisement placed in the school newspaper. All volunteers were informed that their participation was voluntary and confidential and were asked to sign a consent form indicating any potential risks involved in participation (see Appendix A). They were also told that they could discontinue their participation at any time and that their names and any other identifying information gathered would not be used to identify them in the study.

Any potential volunteer was excluded from this study if answers to a screening questionnaire (see Appendix B) revealed a history of any of the following: head injury, substance abuse, learning disability, neurological disorder, family history of learning disability, significant known abnormality involving the endocrine system, use of steroidal medication within the past three months, familiarity with the test materials, or insufficient fluency in the English

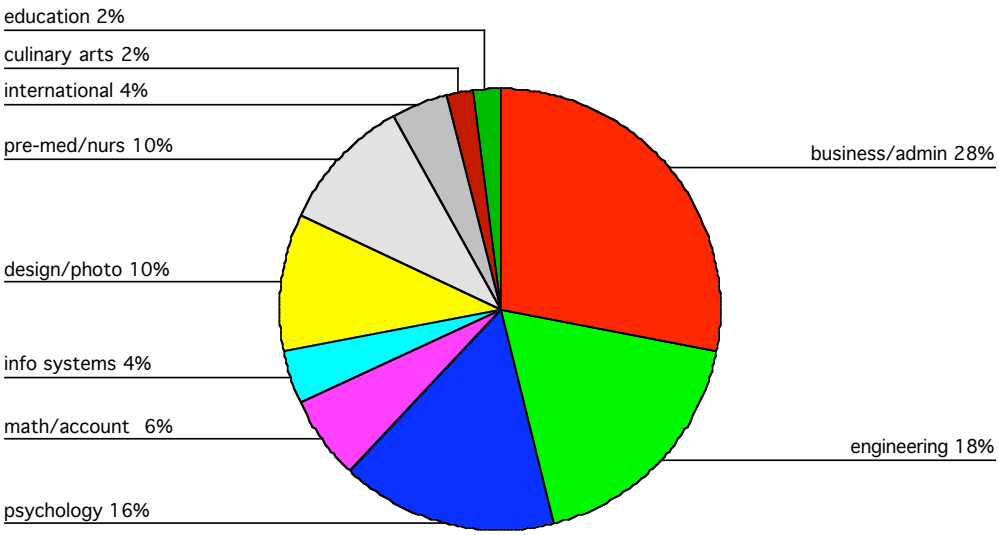

Figure 1. Percentage Breakdown of Participants by Academic Major

language to complete the testing. Any potential participant who was left-handed, adopted or otherwise could not reliably determine the handedness of his or her genetically-related immediate relatives was also excluded. In addition, any woman who was pregnant or had been taking a hormonally based form of birth control within the past three months was eliminated from the pool of potential participants. All of the women who participated in this study reported having had a regular menstrual cycle for at least the past three months. A regular cycle was defined as one with a predictable length (the same number of days each month) of between 25 and 35 days, with no intermittent irregular

bleeding. The average cycle length for the women in this sample was 28.65 days (sd=1.98). Of the female participants, 38% reported past use of oral contraceptives.

All participants were financially compensated for their time. Participants were paid $5.00 for the first session and $10.00 for the second session attended. Those participants completing both test sessions were also entered into a drawing with a chance to win $100.00.

Out of the 90 people who completed the screening questionnaire, 19 were excluded because they did not meet the criteria for the study. An additional twenty-one potential participants did not complete the study due to scheduling difficulties or because they decided not to continue their participation. Table 1 provides a breakdown of the number of potential participants excluded from the study based on the various criteria.

Qualifying participants were assigned to one of two family handedness groups based on their responses to a family handedness questionnaire.

1. FS- group (n=25): right-handers (+9-+24 on The Handedness Inventory) with no left-handed biological relatives including parents, parent's siblings, siblings, and grandparents.

2. FS+ group(n=25): right-handers (+9-+24 on The Handedness Inventory) with at least one left-handed biological relative as defined above.

Table 1. Excluded Potential Participants

History of learning disability/ Family history of learning disability	2
Could not determine handedness of biological Relatives	3
Language difficulties	2
Did not score in right-handed range	1
Hormonal problems/on hormonal medication	3
Neurological disorder	1
Familiarity with test materials	1
Irregular menstrual cycle	6
Unable to schedule/did not come in for first Appointment	13
Discontinued after first session	8

Participants in the FS+ group all reported having one or more full biological relative that was left-handed. Of the 25 individuals in the FS+ group, 21 reported that at least one member of his or her immediate family (parent or full sibling) was left-handed. Eleven FS+ participants reported two or more relatives were left-handed. Table 2 breaks down the percent of FS+ individuals reporting each relational category of biological relative as being left-handed.

Table 2. Percent Participants Reporting Each Relation as Left-handed

Relationship to Participant	*Percent of FS+ group endorsing*
Mother	11%
Father	19%
Sister	21%
Brother	26%
Aunt	5%
Uncle	5%
Grandparent	21%

Each family handedness group was further divided into two subgroups based on sex (male and female). As described in the procedure below, all subjects were then randomly assigned to receive either form I or II of the test materials. Female participants were also randomly assigned to begin testing either during menstruation or at a time estimated to coincide with the late follicular phase of their menstrual cycle. For distribution of groups, please see figure 2.

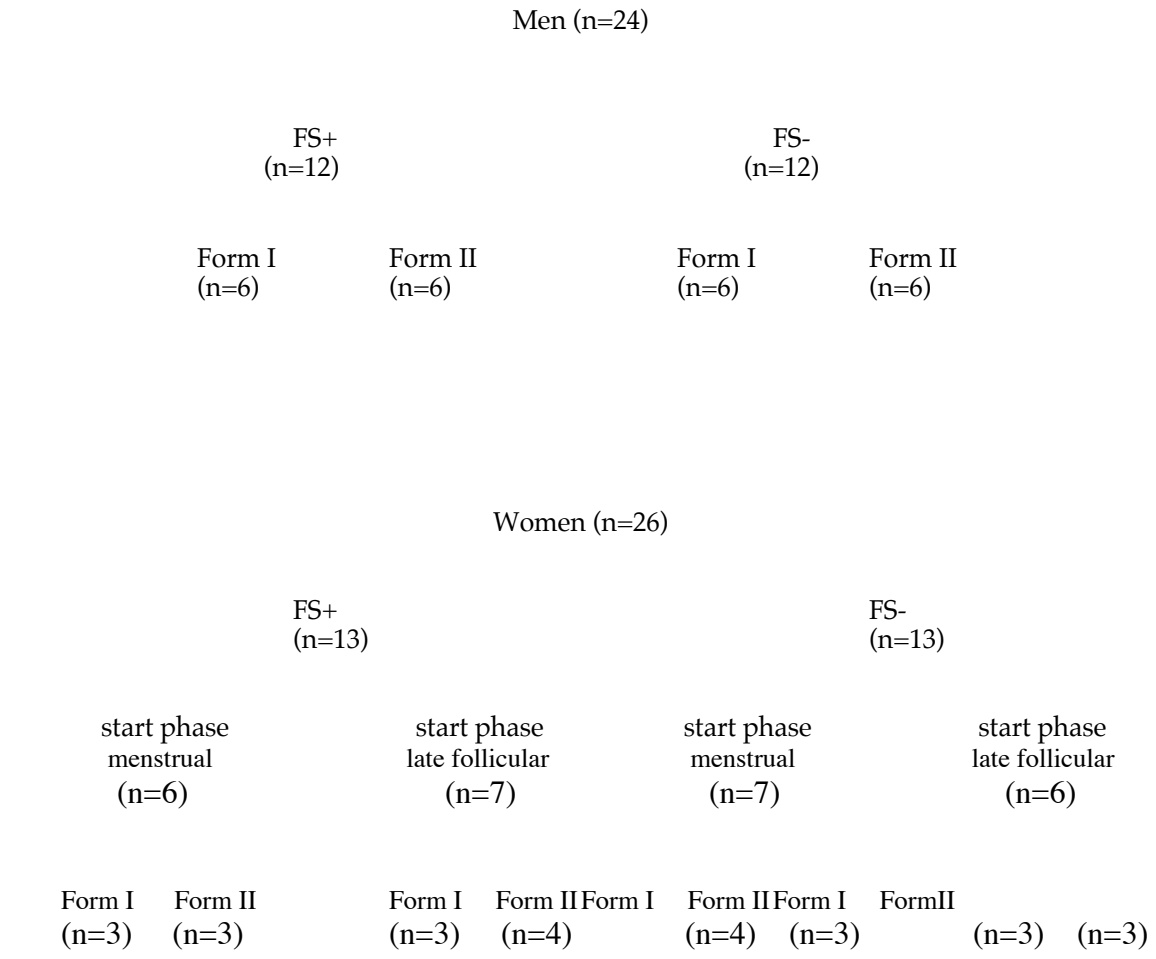

Figure 2. Distribution of Groups

3.2 Materials

Screening Questionnaire. A questionnaire developed for this study (see Appendix B) was used to screen potential subjects for appropriateness to the study and to determine group membership. This questionnaire was based on one used in a previous study (D'Andrea, 1998).

Background Information Form. This form was used to assess demographic and background information (See Appendix C) and was based on one used in a previous study (D'Andrea, 1998).

The Handedness Inventory. The Handedness Inventory (Briggs & Nebes, 1975) is a revision of Annett's (1967) questionnaire; with the primary change being that it allows for greater sensitivity to mixed hand preference. It consists of twelve questions about hand preference for a number of everyday activities such as writing, throwing a ball, and brushing teeth (see Appendix D). Participants indicated degree and direction of hand preference for each activity on a five-point scale ranging from "always left" to "always right". Scores can range from -24 (strongly left-handed) to +24 (strongly right-handed). The authors of this test have set a cutoff score of +9 or above to be identified as right-handed. This measure was used to verify right-handedness.

The Asher Test, This test was used to determine eye dominance (cited in Gur and Gur, 1977). Subjects were seated across from the examiner and asked to hold their hands at face level with their palms facing them. They were then instructed to bring their hands together until all that can be seen is the

examiner's nose. The eye aligned with the slit between their hands was noted as the dominant eye. This procedure was repeated twice.

Weschler Adult Intelligence Scale-Revised (WAIS-R) Digit Span Subtest. This test was administered to estimate span of immediate recall for a verbally presented sequence of numbers and was administered according to standard procedure. Subject comparisons were made using age-corrected scaled scores.

Weschler Memory Scale-Revised (WMS-R) Visual Span Subtest. This test was used to estimate span of immediate recall for a visually presented sequence. Subjects were shown a card depicting a non-linear configuration of dots. The examiner tapped the dots in a predetermined sequence that increased in length over the trials. This test was administered according to standard procedure.

Rey-Osterrieth Complex Figure Test (CFT). The CFT (Rey, 1941,1964; Osterrieth, 1944) served as a measure of visuospatial organization strategy and incidental memory for visual material. Subjects were presented with a complex figure to copy (see Appendix E). The stimulus figure was then removed, and the subject was asked to draw it from memory without prior warning. A second memory trial was done after thirty minutes. Subjects copy drawings were scored for organizational strategy using the continuation and symmetry measures described by Bennett-Levy (1984) (see Appendix F). This scoring method was used because it allows for the assessment of copy strategy with minimal cueing and interruptions to the spontaneity of the drawing. The subjects were also scored for the number of features accurately recalled in the immediate and delayed trials.

Verbal Digit Memory Task. The Verbal Digit Memory Task (VDMT) was used as a verbal interference task for some of the Vandenberg and Kuse Mental

Rotation Test (VMRT) items (described below). It was based on a task described by Pezaris and Casey (1991) and consisted of eight pairs of seven-digit series. The first series of digits in each pair was determined using a table of random numbers. In four of the pairs, the second series was identical to the first. In the other four sets, the second series differed from the first (one digit in the second series is higher or lower by one). For each item, a series of seven digits was read aloud at a rate of one per second. Subjects were instructed to try to remember the series by saying the numbers to themselves continuously while performing the mental rotation task. After thirty seconds, the second series was read and subjects indicated whether it was the same or different from the first series. Two separate versions of this task were used, each consisting of eight item pairs. One version was given with items 5-8 and 17-20 from form A of the VMRT and the other with the same-numbered items from Form B of the VMRT as part of the verbal interference paradigm described below. For each item, subjects were scored for the number of items correct.

Visual Memory Span Task. The visual memory span task (VMSP) was an adaptation of the visual span task used in the Wechsler Memory Scale-Revised (WMS-R) and was used to provide visual interference for use with items 9-16 of the VMRT items (described below). The stimulus consisted of a card depicting a non-linear configuration of eight dots in an invisible 5 X 5 grid. The examiner tapped the dots in a predetermined sequence of seven. The participant was instructed to try to remember the sequence by continuously imagining how it looked while performing a mental rotation problem. After a thirty-second delay, a second sequence of taps was presented. In four of the pairs, the second configuration was identical to the first. In the other four sets, the second

configuration differed from the first (one dot was moved by one grid point). Subjects then indicated whether the two items were the same or different. As with the verbal digit memory task, two separate versions of this task were used. Each version consisted of eight pairs of tapping sequences. At each of the two testing sessions one version was given as part of the verbal interference paradigm in the mental rotation task described below.

Vandenberg and Kuse Test of Mental Rotation (VMRT forms A and B). Spatial orientation ability and strategy use was assessed using the Revised Vandenberg and Kuse Test of Mental Rotation (Peters et al., 1995) which is based on the original test developed by Vandenberg & Kuse (1978), using stimuli designed by Shephard and Metzler (1971) (for sample items, see Appendix G). The Vandenburg and Kuse test is among the most commonly given in studies of mental rotation and tends to be more challenging and more sensitive to sex differences than other similar tests (Linn and Petersen, 1985). The redrawn version was created due to deterioration of existing versions of the original test and exists in two versions found to be of similar difficulty (Peters et al., 1995) and was used with the permission of the author. In this task, a line drawing of a three-dimensional figure was presented. Subjects were asked to determine which of four alternatives would accurately represent the stimulus figure if it were rotated in space. Two of the alternatives were correct and two incorrect for each item. Scores were based on the number of items in which both choices were correct.

The administration of this test was adapted for use in the verbal and visual interference paradigm to attempt to differentiate between those using more verbal/analytic vs. a spatial/holistic strategy to solve the problem. Eight

such items were completed without interference, eight with verbal interference and eight with visual interference. In order to control for practice effects, order of presentation in the three conditions were as follows: four without interference, four trials with verbal interference, eight trials with visual interference, four trials with verbal interference, and four trials with no interference. For each of the trials, participants had up to 30 seconds to complete each rotation problem. Each of the verbal interference trials was conducted by having the subject first listen to a series of seven numbers read aloud at the rate of one number per second. Participants were asked to remember the series while they completed one item of the mental rotation task. After 30 seconds, a second series of digits was read aloud. The subject then decided if the second series was the same or different than the first one. The visual interference trials were conducted in a similar fashion to those in the verbal interference condition, the one difference being that subjects attempted to retain a visual sequence of dots while completing each of the mental rotation trials. Strategy scores were determined by calculating a differential between the number of rotation items correct for the verbal interference trials minus the number of rotation items correct for the visual interference trials. Higher numbers, therefore, reflected more difficulty completing the task during visual interference trials than with verbal.

The Finger Tapping Test. The Finger Tapping Test (Reitan and Davison, 1974) was given as measures of relative right and left-hand skill and motor speed. It consists of a tapping device that records the number of times the index finger can tap over ten seconds. This task was repeated for each hand, alternately, until five consecutive trials were obtained that didn't vary by more than five taps (to a maximum of ten trials per hand). Results for each hand were

obtained by the average of the five scores for each hand. Relative hand skill was assessed by a right-hand minus left-hand (R-L) differential.

The Grooved Pegboard Test. This task assesses both hand motor speed and eye-hand coordination. This test consists of a pegboard with a 5 X 5 array of slotted holes angled at different directions and metal pegs that fit into the holes on the board. Subjects were timed as to how long they take to fit the pegs into the holes using only their dominant hand. The test was repeated using their non-dominant hand. As with the Tapping Test, a right-hand minus left-hand differential was determined in order to get a measure of relative right and left-hand skill and motor speed.

The Truck Test. This task is part of the Computerized Neuropsychological Scan and was developed on Macintosh computers using PowerLaboratory (Chute and Westall, 1997). Participants completed this test on an Apple iBook running the appropriate software. This task consists of nine problems in which the participant is asked to indicate which of 7-8 choices best depicts the proper orientation of a hanging chain or water surface in a given picture. Each participant was scored by number of items correct and for average reaction time.

Penn Face Memory Test (PFMT). This task (Gur et al, 1993) is described in Gur et al (2001) and is part of the Computerized Neuropsychological developed on Macintosh computers using PowerLaboratory (Chute and Westall, 1997). Participants were shown twenty target faces generated by software pre- loaded on an Apple iBook laptop computer. All of the faces were devoid of obvious emotional expression and were shown in the form of black and white photographs that included a mix of males and females of various ages and racial/ethnic backgrounds. An immediate recall recognition trial was conducted

in which the target faces were shown interspersed with twenty distracter faces. For each face shown, subject indicated on a four-point scale (definitely yes, probably yes, probably no, definitely no) if the face was one of the targets or not. A delayed trial was conducted after 20 minutes using the target faces and twenty distracter faces. Performance was assessed by number of correct responses (immediate and delay recall) and reaction time for correct responses.

Controlled Oral Word Association (COWA). This is a test of verbal fluency in which subjects have one minute to list as many words as they can beginning with a given letter. In each test session three different trials were administered. In one of the two sessions, the letters F, A, and S were used. In the other session, C, F, L. Subjects were scored by the number of words they listed over the three trials, excluding perseverations, proper nouns, and non-words.

Salivary samples. Saliva samples were obtained at each of the two visits (see Appendix H for sampling procedure) using kits provided by Pharmasan Laboratories. Materials for saliva collection included a small plastic vial with cap, label for subject number, and a parafilm square used for stimulating saliva flow. Every effort was made to ensure that all saliva samples were collected at the same time of day for each subject. Pharmasan Laboratories conducted an analyses of estradiol and testosterone levels (see Table 2) on each of the samples. In order to insure subject confidentiality, only subject numbers were used to identify the samples.

Post-Testing Questionnaire. This brief questionnaire was developed for use in this study in order to obtain feedback about test difficulty and strategies used to solve some of the problems (see Appendix I).

3.3 Procedure
3.3.1 Screening and Scheduling

Potential subjects were recruited from Psychology classes at Drexel University and from an advertisement in the *Drexel Triangle* newspaper. Any individual expressing interest in participation was initially sent a letter via electronic mail briefly describing the study and listing the major inclusion criteria (see Appendix J). Those individuals who felt they met the requirements for participation and who remained interested in volunteering were instructed to contact the examiner for a brief screening interview over the phone. All phone screenings were done via a questionnaire (see Appendix B). This questionnaire included general health questions aimed at determining if there were any medical conditions or other factors that would preclude the individual from participation. Information about familial handedness was also gathered based on the handedness of genetically related siblings, parents, parental siblings, and grandparents. Any potential participants who were unsure of the handedness of any of these relatives were given the opportunity to gather this information directly from their family member(s). Those participants who met the criteria for inclusion in the study and who agreed to continue their participation were scheduled for the first of two individual testing sessions to be conducted by the examiner. All sessions lasted approximately 1.5 hours and took place in a private testing room within the Psychology Department at Drexel University.

3.3.2 Random Assignment

Because alternate stimuli were used for some of the repeated measures, participants were randomly selected to get Form I or Form II of the testing materials. Both forms were identical with the exception that participants taking Form I were given Form A of the VMRT, verbal digit memory task, visual memory span task, and the FAS version of the COWA at the first session. They then received Form B of the VMRT, verbal digit memory task, visual memory span task and CFL version of the COWA at session two. Participants given Form II of the test materials were given the stimuli in the reverse session order (to see form I of test materials see Appendices L and M).

Female participants were also randomly assigned to begin testing at a time estimated to correspond either with the menstrual or late follicular phase of their menstrual cycle. The second session was then conducted during the alternate phase for each woman. Random assignments were made by placing each qualifying female participant in the next available test form/cycle phase slot based on her family handedness group (see Appendix K for a blank copy of the assignment sheet used for female participants). Timing of the initial test session was counterbalanced so that half of the women in each of the family handedness groups (FS+ and FS-) had their first session during the menstrual phase and half during the late follicular phase. Cycle phase was determined by each woman's cycle length and the first day of her last menstrual period. Testing sessions occurring during the menstrual phase were typically conducted between the third and fifth day of each woman's cycle. Whenever possible, women were not tested during the first two days of their cycle due to the possible confounding

effect of physical discomfort during this time. Late follicular testing occurred fourteen days prior to the expected onset of their next menstrual period.

For both male and female participants, the two sessions were approximately two weeks apart and every effort was made to make the two sessions at the same time of day. At the time of scheduling, participants were given information about reimbursement for participation and were instructed not to eat, drink, chew gum or brush their teeth one hour prior to the session so that the hormone analysis will be as accurate as possible.

3.3.3 First Testing Session

At the initial visit, all participants were presented with a consent form explaining the nature of the research as well as the confidentiality of the experiment (See Appendix A). Prior to signing the consent form, participants were asked to demonstrate understanding of the document by answering the following questions as outlined by the procedures given by the Office of Research Compliance, Drexel University College of Medicine:

1. What is the purpose of this study?
2. What will be done?
3. What risks and discomforts may occur from participating in this study?
4. What benefits may the participants gain from participating in this study?

Once the participant demonstrated understanding of the consent document and written informed consent was obtained, saliva samples were collected (See Appendix H for procedure used in the collection of saliva samples).

All participants filled out a brief background information form (see Appendix C) and the Handedness Inventory (see Appendix D) as described

earlier. Each participant was also given the Asher Test to determine eye dominance. (to see instructions given to participants at tests session one, see Appendix L). Twenty-four items of the Revised Vandenberg and Kuse Mental Rotation Test were administered (eight without interference, eight with verbal interference, and eight with visual-spatial interference) as outlined above. Finger tapping was given in accordance with standard procedures. The next test introduced in this session was the Penn Face Memory Test (encoding trail and immediate recall). The Grooved Pegboard Test, the Controlled Word Association Test and the Truck Test followed this. The final task was the delayed recall for the Penn Face Memory Test. At the completion of the first testing session, all participants were compensated for their participation with $5.00 cash and their second session appointment was made. A few days prior to the second session, participants were sent an e-mail reminding them of their final appointment.

3.3.4 Second Testing Session

Participants attending the second individual testing session were given a repeat saliva test as described above. Appendix M provides instructions given to participants for the various tests at session two. Participants were then given the Rey-Osterrieth Complex Figure Test. They were told to copy the figure presented to them. The examiner made her own drawing, using directional arrows and numbers to indicate the order and organizational flow of the participants copy drawing. After the participant completed the copy, the stimulus and copy was removed from view and the participant was asked to recreate the figure to the best of his or her ability from memory without prior warning. At the end of this

testing session, participants were asked to draw the Rey-Osterrieth Complex Figure a second time from memory.

The Information (INFO) and Block Design (DS) subtests of the WAIS-R were then given to all participants in accordance with standard procedure. The Digit Span task, visual memory task, mental rotation, and the COWA test were given as outlined above using alternate stimuli. The Finger Tapping test, Grooved pegboard task, Penn Face Memory, and the Truck Test were also repeated in the second session. At the end of this test session, participants were asked to recall the Rey Osterrieth Figure and to answer questions about their use of strategy during some of the tasks as part of a post-testing questionnaire (See Appendix I). All participants completing the second testing session were given $10.00 cash as a financial compensation and entered into a random drawing for a chance to win $100.00 . In order to avoid bias, all tests were scored after all data collection was completed without knowledge of group membership (sex or family handedness) or cycle phase. Analysis of salivary estradiol and testosterone was conducted by Pharmasan Laboratories.

3.3.5 Follow-up

In order to verify that session two likely occurred in the late follicular phase for the women who started in the menstrual phase, these participants were contacted by e-mail approximately two weeks following their second testing session. Each participant was instructed to send a reply e-mail indicating the start date of her first menstrual period following the final testing session. For an overview of the measures and procedure used, please see Appendix N.

4. Results

In order to determine whether or not the four sex and family handedness groups were matched on the potentially confounding demographic variables of age and years of education (EDU), as well as for general fund of information, separate analyses of variance (ANOVAs) were conducted for age, education, and WAIS-R Information (INFO) age-corrected scaled scores. These analyses showed no significant differences between the sex and family handedness groups on any of these variables. A comparison of means was also conducted to look at any potential differences between the four groups on the Handedness Inventory (HI), Finger Tapping Test (TAP) right- minus left-hand differential or the Grooved Pegboard Test (PEG) right- minus left-hand differential. A right-hand advantage was found for participants in all groups across self-report (HI) and performance measures (TAP and PEG), with no significant differences found between groups on any of these measures. Table 3 provides means and standard deviations for the overall sample and for each group for Age, EDU, INFO, HI, TAP and PEG.

Because participants were given alternate versions, counterbalanced across sessions, of the Controlled Oral Word Association Test (COWA), Vandenberg and Kuse Mental Rotation Test (VMRT) and the verbal and visual interference tasks, within-subject comparisons were made for overall performance on the two forms of each of these tasks. Paired samples T-tests revealed no significant performance differences (number of words generated) for the CFL versus the FAS version of the COWA. Similarly, no significant differences were found between alternate versions (A and B) of the VMRT,

verbal interference sequences (VDMT), or visual interference sequences (VMSP) in terms of number of items correct. Table 4 provides performance means and standard deviations for each version of the four tests that were given in alternate forms.

Table 3. Group Means for Demographic and Handedness Variables and Info* Scores

Variable	All Subjects (n=50)		FS+Male (n=12)		FS-Male (n=12)		FS+Female (n=13)		FS-Female (n=13)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Age (years)	20.7	3.1	21.7	3.2	20.8	1.7	20.8	4.3	19.8	2.5
Education (years)	13.9	1.5	14.0	1.3	13.9	1.3	14.0	1.7	13.8	1.8
Information*	11.6	1.8	12.3	1.9	11.4	1.5	11.8	1.4	11.0	2.1
Handedness Inventory	19.7	3.5	19.4	3.2	19.9	3.9	20.3	2.9	19.2	4.1
Tapping (R-L)	4.4	4.2	4.2	4.9	5.0	3.8	5.8	3.6	2.4	4.0
Pegboard (R-L)	-7.4	10.0	-5.9	8.6	-8.6	15.1	-7.2	7.2	-7.8	9.1

*WAIS-R Information subtest age-corrected scaled scores

Table 4. Comparisons of Mean Performance for Alternate Versions of Repeated Measures*

Test	$\bar{X}$ performance	SD
	COWA	
FAS	41.2 words	11.74
CFL	41.4 words	11.11
	Vandenberg MRT	
Form A	16.5 items correct	5.08
Form B	17.1 items correct	5.32
Verbal Distraction (VDMT)		
Form A	6.0 sequences correct	1.55
Form B	6.3 sequences correct	1.63
Visual Distraction (VMSP)		
Form A	5.9 sequences correct	1.47
Form B	5.9 sequences correct	1.23

*There were no significant differences between alternate versions for any task.

4.1 Sex x Family Handedness x Test Session
4.1.1 Practice Effects

In order to examine possible main and interaction effects for sex and family handedness (hypotheses 1-3), a 2 (sex) X 2 (family handedness) X 2 (test session) MANOVA was conducted for the repeated cognitive and motor measures. Initially, results were examined for possible practice effects across or between the four sex/family handedness groups. The mean number of days between sessions for all participants was 15.02 (SD=3.89), with no significant difference between groups for number of days between sessions. A significant

main effect F (13,34)=42.03 (p<.0001) was found for test session, with participants in all four groups showing significant improvement between test sessions one and two on the majority of repeated dependent measures. Univariate tests indicated significant practice effects for 10 of the 13 dependent measures (see Table 5 for an overview of mean performance for the four groups on repeated measures). The MANOVA was not significant for overall interactions between test session, sex, and family handedness. Of those tests showing significant practice effects, all but one (COWA) showed significant improvement across all sex and family handedness groups. On the COWA, a family handedness x session effect was found F(1,46)=7.08 (p=.01), with FS- participants showing greater improvement from test session one to test session two than the FS+ participants. Although all groups improved significantly on the VMRT, women showed a greater improvement F (1,46)=6.53 (p=.014) in number of items correct over men.

4.1.2 Sex x family handedness

A main effect for sex (favoring men) was expected on spatial measures (hypothesis 1). Sex differences were also predicted for motor measures, with men being expected to outperform women on TAP and women being expected to be top performers on PEG (hypothesis 2). As expected, a significant overall main effect was found for sex F (13,34)= 4.46 (p<.0001). Univariate F-tests were significant for the VMRT, with men outperforming women for the number of rotation problems solved correctly F (1,46)=5.90 (p=.019).

Table 5. Mean Performance at Session One and Two by Group

Test		FS+Male (n=12) $\bar{x}$	FS-Male (n=12) $\bar{x}$	FS+Female (n=13) $\bar{x}$	FS-Female (n=13) $\bar{x}$
Peg R	1	69.1	66.4	57.1	63.2
(seconds)	2	65.3	64.8	56.8	59.9
Peg L +	1	75.0	75.0	64.0	70.9
(seconds)	2	76.1	72.3	62.5	69.4
Tap R	1	57.4	56.4	54.5	49.8
(#taps)	2	58.0	58.3	56.1	51.9
Tap L *	1	53.2	51.4	48.7	47.4
(#taps)	2	53.8	52.5	50.0	48.0
VMRT ***♣	1	17.8	17.3	13.3	13.3
	2	19.5	19.2	17.0	17.4
TRUCK *	1	5.3	4.2	4.1	3.2
	2	5.9	4.3	4.7	3.7
Truck ***	1	20296.58	19407.0	23053.69	20301.46
(rx time)	2	12909.75	11775.0	11182.15	11261.31
Face im***	1	34.6	29.3	33.5	32.4
	2	36.2	32.8	35.9	35.5
Facedel ***	1	34.5	32.7	34.5	33.5
	2	36.4	33.8	36.2	36.5
face im	1	1485.35	1617.71	1605.35	1944.79
rx time ***♦	2	1254.65	1390.17	1266.67	1559.60
face del 1		1292.90	1504.17	1261.46	1492.04
rx time ***	2	1134.96	1191.58	1089.69	1232.69
fluency ♦	1	44.17	34.67	42.31	41.85
	2	41.67	40.17	42.15	43.23

significance of overall practice effects:

+ p<.05 ♦family handedness (greater improvement for FS- than FS+)
*p<.01 ♣sex (greater improvement for women than men)

**p<.001 ***p<.0001

However, the other repeated visuospatial measures (Face Test, Truck Test, and VMRT strategy) did not show significant sex differences on the univariate tests. On the motor tasks, significant sex differences were found in the expected directions. Men outperformed women on finger tapping for both the right F (1,46) = 9.46 (p=.004) and left F (1,46)=7.50 (p=.009) hand. Women significantly outperformed men on the grooved pegboard task for the right hand F (1,46) =8.37 (p=.006) and the left hand F (1,46)=4.96 (P=.031).

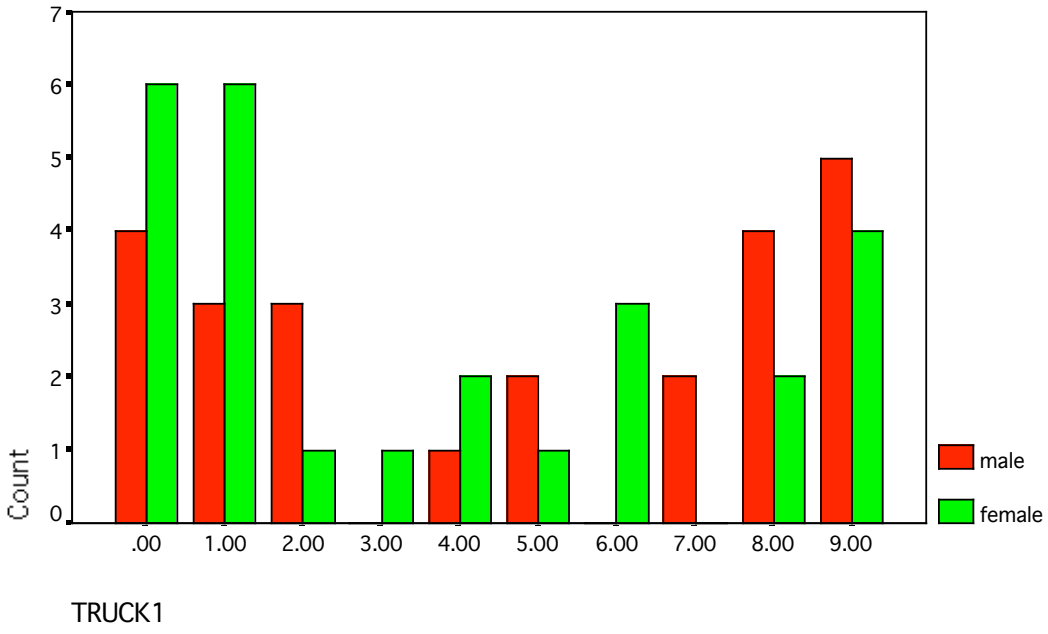

Figure 3. Truck Test Performance by Sex

No overall main effect was found for family handedness on repeated measures, although univariate tests showed a significant effect for familial sinistrality on the VMRT strategy measure that looked at vulnerability to verbal versus visual interference F (1, 46) = 4.82 (p = .033). FS+ men and women performed better on the Vandenberg (items correct) during verbal interference than visual interference trials. The reverse pattern was found for FS- participants, who did better overall on those VMRT trials given with visual interference than those with verbal interference. This difference could not be accounted for by between-group differences in ability to perform the distraction portion of the task. There were no significant group differences in ability to perform the distraction portion of the adapted VMRT (number of verbal or visual sequences correct) or in overall ability to recall numerical or visual sequences as assessed by the WAIS-R Digit Span (DS) or WMS-R Visual Span (VS) subtests. FS+ participants also did significantly better than FS- on three of the four measures used for the Face Test (Immediate recall, immediate recall reaction time, delayed recall reaction time). No significant overall sex x family handedness interactions were found for any of the repeated measures, although univariate tests showed a sex x family handedness interaction for immediate recall of faces F (1,46)=3.78 (p<.058), neared significance with FS+ men being the top performers (see Table 6).

Separate 2 (sex) x 2 (family handedness) ANOVA s were conducted for the non-repeated measures (REY and BD). No main effects for sex or family handedness were found. As expected, (hypothesis 3), a significant sex x family handedness effect was found for the REY, with FS+ women outperforming other groups on immediate recall for the REY F (1,46)=4.25 (P<.045) and REY strategy F

(1,46)= 4.77 (P<.034). Table 7 provides means and standard deviations for non-repeated measures by group.

Table 6. Univariate F-tests for Sex x Family Handedness MANOVA for Repeated Measures

	Sex		Family Handedness		sex by family Handedness	
	F	Sig. of F	F	Sig. of F	F	Sig. of F
Measure						
VMRT						
Number correct	5.90	.019*	.01	.920	.06	.805
Strategy	.01	.944	4.82	.033*	.72	.401
Face Test						
Immediate Recall	1.38	.247	7.20	.010*	3.78	.058
Delay Recall	.62	.433	1.57	.216	.96	.331
Im. Recall RT	2.30	.136	4.73	.035*	.77	.383
Delay recall RT	.03	.857	5.90	.019*	.16	.691
Truck Test						
Number correct	1.06	.309	1.35	.251	.04	.838
Reaction time	.03	.864	.33	.569	.01	.937
COWA						
Number of words	.51	.481	.69	.409	.87	.357
PEG						
Right hand	8.37	.006*	.40	.546	1.56	.217
Left hand	4.96	.031*	.37	.546	1.52	.224
TAP						
Right hand	9.46	.004*	2.76	.104	2.06	.158
Left hand	7.50	.009*	1.08	.305	.00	.983

Table 7. Mean Performance for Sex and Family Handedness Groups on Non-Repeated Measures

Measure	Group			
	FS+/male (n=12)	FS-/male (n=12)	FS+/female (n=13)	FS-/Female (n=13)
	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD
Block Design +	12.9 (3.2)	13.1 (3.0)	13.5 (1.9)	11.5 (2.1)
Rey Im. Recall */+	24.0 (7.3)	25.8 (5.9)	25.9 (7.2)	19.5 (7.2)
Rey delay Recall +	24.4 (6.5)	24.1 (6.8)	25.8 (6.2)	19.9 (6.6)
REY strat */+	18.7 (6.8)	20.0 (7.2)	23.8 (6.4)	16.9 (6.4)

* significant for sex x family handedness ($p<.05$)

+significant between FS+ and FS- women ($p<.03$)

In sum, the sex by family handedness MANOVA for repeated measures revealed a significant main effect for sex, with differences found on VMRT and TAP (favoring males) and PEG (favoring females). Male spatial advantage was primarily found on the mental rotation task. Expected sex differences on the Truck Test were not found. Figure 3 shows performance (number of items correct) for male and female participants on this test. In general, the majority of participants were consistent in their performance over the nine trials. No overall main effect was found for family handedness or for any interactions on repeated measures. However, univariate tests revealed an overall FS+ advantage for both

men and women on reaction time and immediate recall measures for the Face Test. Family handedness differences were also found for strategy scores on the VMRT. In addition, FS+ women outperformed FS- women on the non-repeated measures (BD and the REY recall and strategy). Although family handedness differences were found on both visual memory tasks (Face recall and REY recall), participants in all groups were able to retain most of what they had originally encoded at delayed recall.

4.2 Family Handedness X Menstrual Cycle Phase
4.2.1 Confirmation of Cycle Phase

Before making within-subject comparisons of performance at the menstrual versus the late follicular phases (hypotheses 4-6) of the menstrual cycle, cycle phase was confirmed by two methods. First, estradiol levels were examined for all female participants through analysis of the saliva samples taken at the two test sessions scheduled to coincide with menstrual and late follicular phases. Of the 26 female participants, the majority (n=22) showed higher estradiol levels during the time estimated to coincide with the late follicular phase than during the menstrual phase. The other 4 women (15%) either did not show a change in estradiol or the difference was not in the expected direction. Second, the number of days between the date of testing estimated to coincide with the late follicular phase and the first day of the next menstrual period was calculated. Mid-cycle testing occurred, on average, 13.35 days prior to the onset of participants' next menstrual period, with no difference in number of days prior to menstruation for either of the family handedness (FS) groups. Onset of menstruation was confirmed either at test session two (for women who

completed session 1 at mid cycle) or via a post-testing follow-up question assessed two weeks after the second test session.

Comparisons were also made to see if there were any differences between FS+ and FS- women for menstrual cycle characteristics (length of average menstrual cycle or change in estradiol levels between the follicular and menstrual phases). No significant between-group differences were found for either of these characteristics. Average cycle length for the entire sample was 28.6 days (sd=2.00), with FS+ women averaging 28.8 days (sd=2.3) and FS- women averaging 28.5 days (sd=1.7). On average, levels of estradiol were significantly higher (p=.001) at mid-cycle than at menstruation (The average change for FS+ women was .40 (sd=.68); for FS- women .46 (sd=.4). As would be expected, there was no significant change in male estradiol levels between session 1 and session 2. Table 8 provides estrogen and testosterone levels for each of the sex/family handedness groups.

Table 8. Estrogen and Testosterone Levels for Sex and Family Handedness Groups by Test Session and Cycle Phase

Variable	All Subjects (n=50)		FS+Male (n=12)		FS-Male (n=12)		FS+Female (n=13)		FS-Female (n=13)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
<u>estradiol</u>										
session1	1.02	.73	.87	.42	1.27	1.09	1.14	.70	.82	.53
session 2	1.05	.93	.97	.33	1.66	1.63	.91	.57	.71	.40
menses	.67	.42	----	----	----	----	.82	.50	.53	.27
mid-cycle	1.11	.62	----	----	----	----	1.22	.71	1.00	.51
<u>testosterone</u>										
session1	45.83	40.46	72.63	24.09	91.08	32.09	13.17	4.49	11.98	5.24
session 2	50.68	51.80	74.96	19.91	109.67	59.59	12.10	6.30	12.41	5.45
menses	11.48	5.08	----	----	----	----	11.48	4.65	11.48	5.66
mid-cycle	13.35	5.39	----	----	----	----	13.79	5.99	12.9	4.91

4.2.2 Family handedness x cycle phase

In order to test the hypothesis that women show performance variations across the menstrual cycle and that spatial ability is favored at menstruation, a 2 (family handedness) x 2 (menstrual cycle phase) MANOVA for repeated measures was conducted for the female participants.

No overall significant main effects for Family Handedness or menstrual cycle phase were found, although women in both family handedness groups performed best during the menstrual phase on delayed recall of faces F (1, 24)=5.74 (p=..048). However, an overall significant effect for family handedness x cycle phase was found F (11,14)=2.68 (p=. 043) with FS+ women tending to show greater performance during menses, and FS- women performing better during the late follicular phase. Although this interaction showed a similar trend for a number of tasks (VMRT, PEG, TAP, COWA), univariate F-tests reached statistical significance only for the COWA F (1, 24)=20.33 (p<. 0001). Table10 gives means and standard deviation for performance of FS+ and FS- women at the late follicular and menstrual phases.

Univariate F-tests showed a main effect for family handedness favoring FS+ women on reaction time for the face test delay recall reaction time F (1, 24)=4.47 (p=.045). and neared significance for immediate recall reaction time F (1, 24)=3.80 (p=.063). A 2 x 2 MANOVA on non-repeated measures found a significant main effect for family handedness favoring FS+ women F (4, 19)=.045 (p=.045) regardless of cycle phase. Univariate tests showed significance across all four measures that included BD F (4, 19)=6.27 (p=.02), REY strategy F (4, 19)=7.31 (p=.013), Rey immediate recall F (4, 19)=5.40 (p=.03) and REY delay recall F (4, 19)=5.88 (p=..024). Because the REY and BD were not repeated at both

test sessions, within-subject menstrual cycle comparisons could not be made for these tests.

Table 9. Female Performance at Late Follicular and Menstrual Phases

	Late follicular		Menstrual	
	M	SD	M	SD
Vandenberg MRT				
No, correct	15.38	5.04	15.12	4.76
Face Test				
Im. Recall	34.38	2.99	34.27	3.21
*Del. Recall	34.46	3.62	35.85	2.56
Truck Test				
No. correct	3.77	3.57	4.20	3.69
Reaction time	17329		15569	
COWA				
No. words	41.65	10.65	43.12	9.17
WAIS-R Digit Span				
Age corr scale score	11.08	1.81	11.00	2.10
WMS-R Visual Span				
Raw score	19.35	2.48	19.12	2.72
Tap				
Right hand	53.37	4.79	52.78	6.60
Left hand	48.62	4.21	48.38	5.49
Difference	4.73	3.49	4.41	4.24
Peg				
Right hand	59.15	6.19	59.35	7.89
Left hand	66.50	12.05	67.00	12.14
Difference	-7.35	8.44	-7.65	7.03

Table 10. Family Handedness Group Performance Means for Women at Late Follicular and Menstrual Phases

	Late Follicular		Menstrual	
	FS+	FS-	FS+	FS-
	$\bar{x}$ SD	$\bar{x}$ SD	$\bar{x}$ SD	$\bar{x}$ SD
Vandenberg (traditional score)	14.5 (5.4)	**16.2** (5.1)	**15.8** (4.9)	14.5 (5.6)
percent visual strategies	62%	38%	**77%**	54%
interference (verb-visual)	-.15 (2.1)	-.38 (2.1)	**+.69** (2.1)	.00 (2.1)
COWA (number words)	39.5 (10.3)	**43.8** (10.9)	**44.9** (9.2)	41.3 (9.1)
Tap (right hand)	54.9 (4.5)	**51.8** (4.7)	**55.7** (7.2)	49.9 (4.6)
Tap (left hand)	48.7 (4.4)	**48.5** (4.2)	**49.8** (6.1)	46.9 (4.6)
Peg (right hand)	57.5 (6.5)	**60.8** (5.6)	**56.5** (6.9)	62.2 (7.9)
Peg (left hand)	63.8 (10.9)	**69.2** (12.9)	**62.8** (7.4)	71.5 (14.6)
Face (Im. Recall)	34.8 (2.8)	33.9 (3.2)	34.5 (2.8)	34.0 (3.7)
Face (Im RT)	1393 (376.4)	1757 (607.1)	1479 (428.7)	1747 (430.5)
Face (delay recall)	34.7 (3.4)	34.2 (3.9)	**35.8** (2.2)	**35.8** (2.9)
Face (delay RT)	1181 (243.6)	1356 (323.7)	1170 (236.8)	1369 (232.3)

4.3 Sex x Spatial Strategy x Test Phase

In order to test the hypothesis that women who use spatial (holistic) strategies show a greater enhancement of spatial performance at menstruation than those who use more verbal (analytic/part-oriented) strategies, it was first necessary to determine whether or not participants consistently used one particular strategy. The data was examined for possible correlation between the two performance measures of strategy (REY strategy scores and VMRT strategy scores) as well as self-report measures (answers to multiple choice questions on the post-testing questionnaire regarding strategy use on the Rey and VMRT). Only two of these measures (REY strategy score and REY strategy self-report) showed a significant relationship ($p=.005$), In order to examine this relationship, Rey strategy scores were classified by split-half as either "high spatial" or "low spatial". Although 56% of all participants reported using a visual strategy on the REY (38% verbal and 6% neither), participants with performance-based"high spatial" strategy scores endorsed using a visual strategy to remember the REY 72% of the time as compared with only 20% of the "low spatial" strategy score performers. Table 11 gives the three possible multiple choice answers along with number of participants endorsing each choice and mean REY strategy score for participants endorsing that strategy.

Other than specifically for the REY, it was not possible to determine an overall (across tasks) strategy style for the participants. Therefore, it was not possible to conduct an analysis looking at performance by overall strategy style (or strategy style by cycle phase). REY strategy scores could not be used alone,

particularly given that the REY was not repeated for within-subject comparison over the menstrual cycle.

Table 11. Comparison of Self-report and Performance-based REY Strategy Scores

Self-report strategy	number endorsing	REY strategy score	
		$\bar{X}$	SD
I tried to picture the figure in my mind and then drew what I saw.	28	21.2	7.26
I named the various shapes and features to myself and then drew them to the best of my recollection.	19	18.58	6.74
I did not use either of those approaches in trying to recall the figure.	3	15.67	2.08

4.4 Hormone levels/Testosterone

To look at possible group differences in T and E, repeated measures ANOVAs were conducted for each of these dependent variables as a function of sex and family handedness. No significant within-subject effects were found for T or E for test session one versus two. A significant sex x family handedness interaction was found for both Estradiol $F(1, 46) = 5.44$ ($p < .024$), and Testosterone $F(1, 46)$

= 6.15 ($p < .017$). FS- men showing higher overall estradiol and testosterone levels than the other three groups. FS+ women showed higher average estradiol at both menstrual cycle phases than FS- women (see Table 8) and higher testosterone at mid-cycle.

To address questions of a possible effect of T on performance initially a Pearson correlation matrix was conducted to examine if any significant relationships were found between absolute T values and performance at the time the saliva sample was taken. Because there was a possibility that women and men might differ in terms of the relationship between performance and T, and because significant differences in T are attributable to sex, possible correlations were examined separately for the two sexes. Once sex differences are accounted for, no significant relationships were found between absolute T and cognitive performance in men and women. Therefore, support was not found for the hypothesis that relatively lower T in men and relatively higher T in women is associated with higher spatial performance. One variable, eye dominance, was found to be correlated with T levels in both men and women $p=.037$, with those participants who were left-eyed having higher T values than those who were right-eyed (right eyed $x=40.28$, left eyed $x=72.80$).

5. Discussion

This study sought first to explore possible interactions between factors that may underlie individual differences in cognitive performance (sex, family handedness, problem solving strategy and testosterone levels) in healthy young adults. Secondly, and perhaps more importantly, the current study was designed to consider the possible impact of these factors on the degree to which cognitive performance might vary over the course of the menstrual cycle. Given the aims of this study, it was important to examine initially which, if any, of the above-mentioned between-subject factors might account for individual differences in performance in general, and in particular, visuospatial performance.

A main effect for sex was found on the VMRT (number of items correct) and motor tasks (TAP and PEG). These results were expected given that sex differences are particularly robust for these tasks. Sex differences on the VMRT and motor tasks found in this study were in the expected direction, with men outperforming women on the VMRT and TAP, and women outperforming men on PEG. However, a male advantage was not found on spatial tasks, generally, supporting the notion that visuospatial sex differences are largely task-dependent. This result is not surprising given that some of tasks used in this study, including the REY and BD, have not been found to detect sex differences consistently over studies (Berry, Allen & Schmitt (1991), Boone, Lesser, Hill-Guiterrez, Berman, and D'Elia, 1993; Rosselli and Ardila (1991).

The results of this study suggest that inconsistent findings of sex differences for some tasks may be due to greater within- than between-sex

variation. Overall, positive results were found for family handedness for the majority of tests that did not show significant effects for sex. These include the Face Test, BD, REY recall, as well as for strategy measures for the REY and VMRT. Significant effects were found for family handedness by sex for the COWA, although this was for session one only. Only one of the tests (Truck Test) used did not show any effect for sex, family handedness or interaction. Although sex differences were expected on the Truck Test, such differences were not found in this study. Although it is not certain why this is the case, this test differs from the others used in terms of being reliant on knowledge of and ability to apply an underlying principle. As stated in the results, most subjects either did well or poorly on this test (see Figure3) demonstrating generalized ability or inability to apply the underlying principle fairly consistently across problems. Therefore, it may be possible that failure to detect differences was reflective of the knowledge base of the sample.

For a number of the measures showing an effect for family handedness, the expected pattern was seen, with women showing a greater effect of family handedness than men. Of the four groups, FS+ women showed the greatest use of "visual" (holistic) strategies on the REY as well as more vulnerability to visual interference on the VMRT. FS- women showed the poorest performance overall, and the greatest tendency toward verbal/analytic (part-oriented) strategies for REY and VMRT of the four groups. Differences between FS+ women and FS- women were greater than differences within men or between women and men not only on these strategy measures, but also for BD, Rey immediate and delay recall.

Some of the possible explanations for negative findings for family handedness in past studies, particularly in studies that did not look at performance separately for women and men are: (1) male performance is less impacted by family handedness, therefore decreasing the overall effect and (2) men show opposite pattern of performance than women so that FS- men would be top performers and FS+ men would perform less well on spatial tasks. The result of this study lends support for the first of these explanations for some tasks (REY, BD, VMRT strategy) where male performance didn't show as much variation as women. There was also some tendency for FS- men to perform better on these tasks than FS+ men, showing some, although weaker, support for the second argument. However, For FACES, FS+ men actually performed at or slightly above the average for female performance, with FS- men significantly below. On this test, female performance varied less than that of men based on family handedness groups. Similarly, FS+ men were the top performers on the COWA (session one only). FS+ men performed somewhat above the level of women and significantly above that of FS- men (averaging ten words less than FS+ men). Therefore, the possibility is raised that although familial sinistrality may be associated with performance differences in both men and women, performance patterns differ as a function of the task at hand. Unfortunately, whether or not there were strategy differences underlying performance variation on the Face Test or COWA could not be determined from this study.

Although it has been suggested that there may be a relationship between testosterone levels and cognitive performance, this was not found in the current study. Since data collection took place over the course of a year, it is possible that this may have been due to seasonal effects of T. In addition, women showed

changes in T over the course of the menstrual cycle, offering another possible confound. However, interestingly, FS- men showed higher levels of both E and T than the other four groups. As stated in the results, eye dominance, was found to be correlated with T levels in both men and women, with those participants who were left-eyed having higher T values than those who were right-eyed. This finding is of interest given that some studies have suggested a relationship between lateral dominance and testosterone in the fetal environment.

The notion that changes in estrogen (E) across the menstrual cycle impacts women as a whole so that increased E is associated with enhancement of performance on verbal and fine motor tasks and a decrease in performance on spatial tasks was not supported. A number of possibilities exist for not finding overall menstrual cycle effects. First, it is possible that women in this sample were not at the optimal time of the cycle to find such effects. For example, it may be that a significant number of women in this study, while having overall higher levels of estradiol at mid-cycle testing sessions than at menstrual phase test sessions, were, nonetheless, not at their optimum estrogen peak or had not had elevated estrogen for a long enough period of time for performance effects to be detectable. A number of studies have compared women at the menstrual versus mid-leuteal phase. Perhaps later in the cycle there has been greater opportunity for the brain to become adjusted to this change in hormonal elevation. Secondly, this study used primarily young women (mean age 20.3). In another study using women of similar age to the present study, no effects were found for menstrual cycle (Epting and Overman, 1998). It has been argued (Epting and Overman, 1998) that women in this age group may have lower hormonal levels than women in their mid-twenties to mid-thirties . In support of this explanation,

women's average salivary estradiol was at the low range of what would be expected in the current study. Third, given that an effect was found in the expected direction (overall better performance during the menstrual phase) for a visual memory task (faces), it may be that this study lacked the necessary power to detect general cycle effects.

However, the results of this study suggest a fourth possibility. In this study, an overall menstrual cycle phase by family handedness interaction was found. While FS+ women saw an increase in performance on a number of tasks at menstruation, FS- women saw an increase in performance on those same tasks at mid-cycle. Although a family handedness by menstrual cycle phase interaction was predicted, it was expected that (1) this effect would be primarily on spatial tasks and (2) the difference in menstrual cycle effect between FS+ and FS- women would be in the degree not the direction of the effect. However, this trend was found for a number of tasks including not only spatial (VMRT) performance , but also motor and verbal. Interestingly, this was most strongly found on a verbal task, the COWA. Unfortunately, why this is the case cannot be determined by this study. It is possible that effects of strategy may come into play. One of the interesting trends seen here is on the VMRT strategy score. Overall, all women tended to be more vulnerable to visual interference during the menstrual phase than during the late follicular phase. However, this went along with increased performance for FS+ women and decreased performance overall in the FS- women. It may be that rather than one strategy being better for everyone, performance is enhanced by using a style that is consistent with relative ability. Therefore, FS- women may actually do better when using a more

verbal/analytic style—and are perhaps best at using their preferred style at a time when the hormonal environment is most favorable to such abilities.

This result may help to explain why studies looking at menstrual cycle effects have been inconsistent. While some studies have found an overall increase in spatial performance during the menstrual phase (Broverman et. Al., 1981; Hampson & Kimura, 1988; Hampson, 1990a), others have failed to find differences (Epting & Overman, 1998) or found enhanced performance on spatial tasks at a time in the menstrual cycle when estrogen was relatively high (Chiarello et. Al., 1989, Janowsky et al, 1998). In addition, a study by Phillips and Sherwin (1992b) also found that about half of the women studied showed opposite performance patterns to what was expected over the course of the menstrual cycle.

The strength of this study comes primarily from its ability to offer some insight into why findings regarding menstrual cycle effects may be inconsistent. It also highlights the importance of looking at between subject factors when looking at any possible within-subject effects such as those that may occur over the menstrual cycle. Particularly important are measures of spatial and verbal aptitude as well as strategy use and strategy preference. While a possible impact of strategy on menstrual cycle effects has been suggested, no known study has looked at this systematically.

This study also raises a number of questions. The first is, what is family handedness actually measuring? The work of Casey and colleagues has used family handedness as a way of predicting group membership based on Annett's right-shift theory as an alternative to looking at relative right- and left-hand skill. However, this study, as well as one before it (D'Andrea,1998) found that FS+ and

FS- women (and in the current study men) did not differ significantly in terms of degree of right-handedness. Future studies are needed to better clarify why a relationship might exist between family handedness and cognitive performance. Given that this relationship seems to vary as a function of sex , task, and strategy it is particularly interesting to consider patterns of performance for tasks in which strategy can be measured. Current findings of significant differences in T and E for the sex/family handed groups also deserve further attention.

While a study such as this one is important for its contribution to a theoretical understanding of brain behavior relationships, there is also potential for practical applications once such relationships are better understood. As stated in previous work (D'Andrea, 1998), understanding factors that contribute to individual differences in specific abilities could eventually lead to estimations of abilities prior to injury or illness that are more finely tuned than those currently available. For example, applying sex-based norms for spatial tasks that favor men to women generally may make it harder to detect small declines in spatial functioning in high ability women resulting from injury or other causes. In that previous work, familial sinistrality was a better predictor of spatial ability than academic major. However, academic major might be more likely to be used as a predictor of ability in clinical practice. Learning more about the possible impact of factors such as family handedness or hormone levels may lead to better prediction of abilities and/or strategy preferences. Specifically, in relation to the possibility that variation in performance may exist within women at various cycle phases, it may be that optimal cycle time for specific tasks differs within women. This suggests important possibilities that run counter to popular notions that women show cognitive decline specifically around menses.

In addition, understanding the relationship between strategy preference, overall ability, and performance may lead to important applications for teaching and training. If we are attempting to teach someone to perform a task optimally, is it preferable to teach what is considered to be the most efficient overall strategy, or the one specific to the person's preferred style? There may be implications for a psychotherapeutic setting as well. It is possible that a better understanding of these relationships may be a way for us to examine how people better respond to interventions using primarily words versus imagery.

One of the weaknesses of this study is that an adequate overall understanding of preferred strategy could not be obtained. Although the strategy measure for the REY was consistent with overall REY performance (those participants who obtained high strategy scores had higher recall scores on the REY) and self-report of strategy use (visualization vs. verbalization), strategy use on the REY could not be generalized to other spatial tasks used. In addition, strategy scores on the VMRT showed variation so that participants did not necessarily use one strategy consistently on this test. This may be due to task demands. In addition, measuring strategy on the VMRT through verbal minus visual interference scores is experimental. Therefore, it is not entirely certain that these scores are an adequate or accurate reflection of the strategy actually used by the participant. An important direction for future research would be to identify more tasks, particularly repeatable ones, in which strategy can reliably be assessed. Of interest would be assessing strategy for both verbal and visuospatial measures.

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APPENDIX A: CONSENT FORM

Drexel University

CONSENT TO TAKE PART IN A RESEARCH STUDY

1. SUBJECT NAME:_____

2. TITLE OF RESEARCH: The Impact of Sex, Family Handedness, and Hormone Levels on Cognitive Ability in Right-Handers.

3. INVESTIGATOR'S NAME: Mary V. Spiers, Ph.D

4. CONSENTING FOR THE RESEARCH STUDY: This is a long and important document. If you sign it, you will be authorizing Drexel University and its researcher to perform research studies on you. You should take your time and carefully read it. You can also take a copy of this consent form to discuss it with your family member, physician, attorney or any one else you would like before you sign it. Do not sign it unless you are comfortable in participating in this study.

5. YOUR RIGHT TO PRIVACY AND CONFIDENTIALITY. Very specific information on your right to privacy and the confidentiality of the use and disclosure of your personal health information can be found at the end of this consent form. We need your authorization to use and disclose the health information that we may collect about you during this research study. To be in this research study, you must read and sign the authorization at the end of this consent form.

6. PURPOSE OF RESEARCH: You are being asked to take part in a research study. The purpose of this study is to help us understand more about the differences in the way men's and women's brains are organized based on how they perform on certain cognitive tasks. The cognitive tasks used in this study are designed to measure different areas such as verbal ability, visual problem solving, attention, and memory as well as fine motor skills. This study will also look at how levels of certain hormones may influence cognitive performance. This study will help us to understand more about how changes in estradiol (a form of the hormone estrogen) over the course of the menstrual cycle may affect some aspects

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of performance in women. The ways in which strength of right-handedness and family handedness patterns affect cognitive and fine motor performance will also be considered. This research project is being conducted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

You have been asked to take part in this study because the answers you provided to the screening questions indicate that you meet the criteria of the study and are thus eligible to participate. You are not eligible to participate if you are left-handed, have a history of significant disease or damage to the central nervous system (e.g. head injury, neurological disorder), are unable to identify the handedness of immediate biological relatives, or are using hormonal medications (e.g. oral contraceptives, corticosteroids). Female participants must also have a regular menstrual period for the past three cycles. A regular menstrual cycle is defined as a 25 to 30 day cycle with no irregular bleeding. Approximately forty-eight Drexel University students will be enrolled in this study.

7. PROCEDURES AND DURATION: As a participant in this study, you will be asked to attend a total of two testing sessions over the course of approximately two weeks. For women, the testing sessions will correspond to specific times during the menstrual cycle. For men, the sessions will occur approximately two weeks apart. Each testing session will last approximately 1.5 hours. Therefore, the entire time commitment for the study is approximately 3 hours. You understand that the following things will be done to you. During your first visit you will be asked to complete two brief questionnaires. One of the questionnaires will assess demographic and background information about yourself. The other contains questions about hand preference for everyday activities. However, this information will be gathered completely anonymously. These questionnaires should take no more than ten minutes to complete. At the first session you will also be given a very brief visual test.

At each of the study sessions you will be asked to complete a number of tests of cognitive function. Some of these tasks will be paper-and-pencil or question-and-answer tasks that will be done with the researcher or her assistant. Two of the tasks will be done independently on a computer. You will also be asked to complete two tests of fine motor function. One of these involves tapping a key with your finger and the other task involves placing pegs in holes.

APPENDIX A: CONSENT FORM

You will also be asked to provide a sample of saliva at each of the two testing sessions. This sample will be analyzed for the presence of the hormones estradiol and testosterone only. The saliva sample takes only one or two minutes to obtain. However, it is important to refrain from any chewing gum, beverages or other food for one hour before providing the sample. The results of all tests administered as part of this study will be used for research purposes only and will not be released to you.

8. RISKS AND DISCOMFORTS/CONSTRAINTS: The risks involved in this study are minimal. It is possible that you may experience some slight discomfort such as mild fatigue, frustration, embarrassment, or anxiety while completing some of the tasks. However, if at any time you choose not to participate in the study, you may withdraw without prejudice.

9. BENEFITS: There may be no benefits to participating in this study. However, there could be a significant benefit gained through knowledge.

10. REASONS FOR REMOVAL FROM THE STUDY: You may be required to stop the study before the end for the following reasons:

    a.) Change in medical condition
    b.) If all or part of the study is discontinued for any reason
    c.) Other reasons, including new information available to the investigator or harmful unforeseen reactions experienced by the subject or other subjects in this study.

11. VOLUNTARY PARTICIPATION: Participation in this study is voluntary, and you can refuse to be in the study or stop at any time without loss of the care benefits to which you are entitled if you should suffer an injury as a result of this trial. Any fee you may be paid will be determined by the amount of time you spend in the trial and, if you do not complete the study, the reason for leaving the study early. The costs involved in conducting this study, including hormonal analysis, are the responsibility of the sponsor, The Institute for Women's Health and The Institute for the Humanities, Drexel University.

APPENDIX A: CONSENT FORM

12. STIPEND/REIMBERSEMENT: You will receive financial compensation for participating in this study. At the end of the first testing session you will receive a payment of $5.00 in cash. At the end of the second testing session you will receive a payment of $10.00 in cash. After completing both test sessions, you will also be entered into a random drawing for a chance to win $100.00. This drawing will take place after all of the participants in this study have completed testing.

13. IN CASE OF INJURY: If you have any questions or believe you have been injured in any way by being in this research study, you should contact Mary V. Spiers, Ph.D. at (215) 895-1722 or Elizabeth D'Andrea, M.S. at (215) 339-8639. If you are injured by the research activity that is underlined in section 6 above, you will be reimbursed/paid for the reasonable costs of medically necessary treatment that is not covered by your health insurance or plan. This agreement to reimburse/pay you does not include treatment for any injury that is not a result of the research activity. No other payments will be made. If you are injured or have an adverse reaction, you should also contact the Office of Research Compliance at (215) 762-3453.

14. CONFIDENTIALITY AND PRIVACY: This section gives more specific information about the privacy and confidentiality of your health information. It explains what health information about you will be collected during this research study and who may use, give out and receive your health information. It also describes your right to inspect your medical records and how you can revoke this authorization after you sign it.

    By signing this form, you agree that your health information may be used and disclosed during this research study. We will only collect information that is needed for the research study. Your health information will only be used and given out as explained in this consent form or as permitted by law.

    In any publication or presentation of research results, your identity will be kept confidential.

APPENDIX A: CONSENT FORM

A. Health information that will be collected

The following personal health information about you will be collected and used during the research study and may be given to others:

- Your name, address, telephone number, e-mail address, and date of birth;
- Personal and family medical history;
- Information from laboratory saliva tests and other tests or procedures described in this consent form;
- Information learned during telephone calls, questionnaires, and individual test sessions done as part of this research study;
- Information about the handedness of family members and your educational background.

B. Who will see and use your health information within Drexel University.

The research study investigator and other authorized individuals involved in the research study at Drexel University will see your health information and may give out your health information during the research study. These include the research investigator and the research staff, the institutional review board and their staff, legal counsel, research office and compliance staff, officers of the organization and other people who need to see the information in order to conduct the research study or make sure it is being done properly.

C. Who else may see and use your health information.

Other persons and organizations outside Drexel University may see and use your health information during this research study. These include:

- Governmental entities that have the right to see or review your health information such as the Office of Human Research Protections and the Food and Drug Administration.
- The Sponsor of this research study and persons that the sponsor may hire to work on this research study. The name of the sponsor is The Institute for Women's Health and The Institute for the Humanities, Drexel University.

If your health information is given to someone not required by law to keep it confidential, then that information may no longer be protected, and may be used or given out without your permission.

APPENDIX A: CONSENT FORM

D. Why your health information will be used and given out.

Your health information will be used and given out to carry out the research study and to evaluate the results of the study.

E. If you do not want to give authorization to use your health information.

You do not have to give your authorization to use or give out your health information. However, if you do not give authorization, you cannot participate in this research study.

F. How to cancel your authorization.

At any time you may cancel your authorization to allow your health information to be used or given out by sending a written notice to the Office of Research Compliance, 245 N. 15th Street, Mail Stop 444, Philadelphia, Pennsylvania, 19102. If you leave this research study, no new health information about you will be gathered after you leave. However, information gathered before that date may be used or given out if it is needed for the research study or any follow-up.

G. When your authorization ends.

Your authorization to use and give out health information will continue until you withdraw or cancel your authorization.

H. Your right to inspect your medical and research records.

You have the right to look at your medical records at any time during this research study. However, the investigator does not have to release research information to you if it is not part of your medical record.

15. OTHER CONSIDERATIONS: If new information becomes known that will affect you or might change your decision to be in this study, you will be informed by the investigator. If you have any questions at any time about this study or your rights as a research subject you may contact Mary Spiers, Ph.D. at (215) 895-1722 and the Office of Research Compliance at (215) 762-3453.

APPENDIX A: CONSENT FORM

16: CONSENT:

- I have been informed of the reasons for this study.
- I have had the study explained to me.
- I have had all of my questions answered.
- I have carefully read this consent form, have initialed each page, and have received a signed copy.
- I authorize the use and disclosure of my personal health information as explained in this consent form.
- I gave consent voluntarily.

Subject or Legally Authorized Representative	Date
Investigator or Individual Obtaining this Consent	Date
Witness to Signature	Date

List of Individuals Authorized to Obtain Consent:

Name	Title	Daytime Phone#	24-Hour Phone#
Mary V. Spiers, Ph.D.	Principal Investigator	(215) 895-1722	(215)895-1722
Elizabeth D'Andrea, M.S.	Co- Investigator	(215) 593-9313	(215)339-8639

APPENDIX B: POTENTIAL SUBJECT SCREENING QUESTIONNAIRE

These questions are aimed at gathering some general background information and to see if you qualify for this study. The answers to these questions will be kept confidential. However, if you are not comfortable answering a particular question, please let me know.

Name_____ Phone (Daytime)_____

Date_____ Phone (Evening)_____

Date of Birth_____ e-mail_____

1. What is your dominant hand?_____

2. Please indicate the handedness of each of the following family members that are **biologically related** to you. If you have more than one family member in a given category (for example, two sisters) please indicate the handedness of EACH of them. Please indicate if there are any family members for whom you are unable to obtain this information.

Family member	Handedness (right, left, ambidextrous)
Sister(s)	
Brother(s)	
Mother	
Mother's siblings	
Father	

APPENDIX B: POTENTIAL SUBJECT SCREENING QUESTIONNAIRE

Family member	Handedness (right, left, ambidextrous)
Father's siblings	
Grandparents	

3. Do you have any history of head injury, seizures, neurological disorder, and/or substance abuse? (If yes, describe briefly).

4. Do you have any hormonal problems (e.g., hypothyroidism)? (If yes, describe briefly).

5. Do you currently take any hormone supplements (e.g. DHEA)?

6. Do you have a learning disability or have any history of learning disabilities in your family? If so, please list the relationship of those individuals (ie: father, sister, etc.) to you and the nature of their disability, if known.

7. Please list any medications that you are now taking.

8. Do you have any history of visual difficulties (describe).

APPENDIX B: POTENTIAL SUBJECT SCREENING QUESTIONNAIRE

Women only:

9. Do you have regularly occurring menstrual cycle, meaning that it occurs every 25-30 days with no spotting in-between?_____

10. If yes, how many days is your cycle on average?_____

11. Have you used hormonal contraceptives such as birth control pill or patch in the past three months?_____

12. Have you ever used hormonal contraceptives?_____

13. When was your last menstrual period (date/month)?_____
How sure are you about that?_____

14. Do you have any menstrual-related problems? (describe)

Qualify Yes No

Group_____

Date of Appointment:

Sub Number____

Qualifiers: When you come in for your first testing session you will fill out a brief questionnaire and will be asked to complete some cognitive tasks. You will also be asked to provide a saliva sample that will be used to test for estrogen and testosterone levels. In order to get an accurate reading, please try to avoid chewing gum, eating food, drinking, or brushing teeth for one hour prior to the test session. If you forget, you should still come to your appointment as scheduled—just notify the examiner. You will be sent an e-mail reminder to confirm your appointment.

APPENDIX C: BACKGROUND INFORMATION FORM

SUBJECT NO._____

Sex (circle one) Male Female

Age_____

Race/Ethnicity (please circle one): Caucasian/White Latino/Hispanic
African American Asian/Pacific Islander
Other (specify)_____

Please indicate which of the following is true for your SAT scores and fill in approximate point difference (you do NOT need to indicate what your actual scores were):

a. My math score was higher than my verbal score by _____points.
b. My verbal score was higher than my math score by _____points.
c. There was no difference between my math and verbal scores.

What is your major field of study and/or professional background?

What reason(s) did you choose your major area of study?

APPENDIX C: BACKGROUND INFORMATION FORM

7. Approximately, how many courses have you taken in your major?

8. Please indicate the highest level of education that you have completed. If currently in school, please indicate current year (i.e.: college freshmen, first year graduate school, etc.)

9. In your own estimation, please rate your ability at the following:

	Excellent	Very good	good	fair	poor
Athletics					
Music					
Math					
Written expression					
Science					
Reading comprehension					
Building things (ie: woodworking)					
Mechanics					
Foreign languages					
Map reading					
Communicating with others					
Visual arts					

APPENDIX D: THE HANDEDNESS INVENTORY

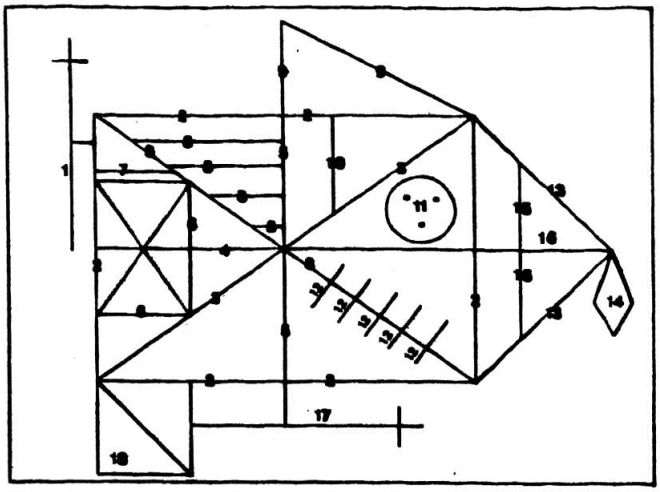
Subject No_____

THE HANDEDNESS INVENTORY

Please indicate your hand preference for the following activities by marking an X in the appropriate box to the right.

Indicate hand preference	Always left	Usually left	No preference	Usually right	Always right
1. To write a letter legibly					
2. To throw a ball to hit a target					
3. To play a game requiring the use of a racquet					
4. At the top of a broom to sweep dust from the floor					
5. At the top of a shovel to move sand					
6. To hold a match when striking it					
7. To hold scissors to cut paper					
8. To hold thread to guide through the eye of a needle					
9. To deal playing cards					
10 To hammer a nail into wood					
11. To hold a toothbrush while cleaning teeth					
12. To unscrew the lid of a jar					

APPENDIX E: REY OSTERRIETH COMPLEX FIGURE



REY–OSTERRIETH COMPLEX FIGURE TEST
FORM A (Rey Figure)

Details:	COPY	DELAY
1. Cross upper left corner, outside of rectangle	____	____
2. Large rectangle	____	____
3. Diagonal cross	____	____
4. Horizontal midline of 2	____	____
5. Vertical midline	____	____
6. Small rectangle, within 2 to the left	____	____
7. Small segment above 6	____	____
8. Four parallel lines within 2, upper left	____	____
9. Triangle above 2 upper right	____	____
10. Small vertical line within 2, below 9	____	____
11. Circle with three dots within 2	____	____
12. Five parallel lines with 2 crossing 3, lower right	____	____
13. Sides of triangle attached to 2 on right	____	____
14. Diamond attached to 13	____	____
15. Vertical line within triangle 13 parallel to right vertical of a	____	____
16. Horizontal line within 13, continuing 4 to right	____	____
17. Cross attached to low center	____	____
18. Square attached to 2, lower left	____	____
TOTAL SCORE	____	____

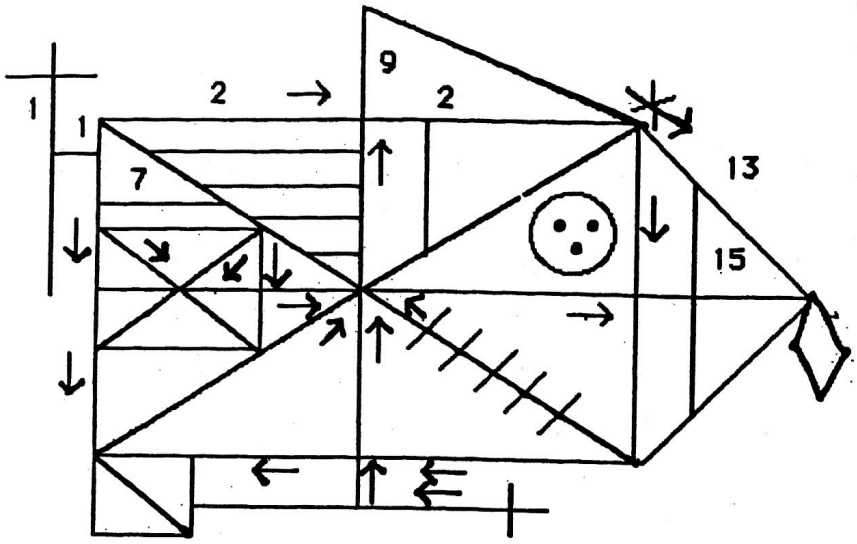
Scoring:

Consider each of the eighteen units separately, and appraise accuracy of each unit and relative position within the whole of the design. For each unit count as follows:

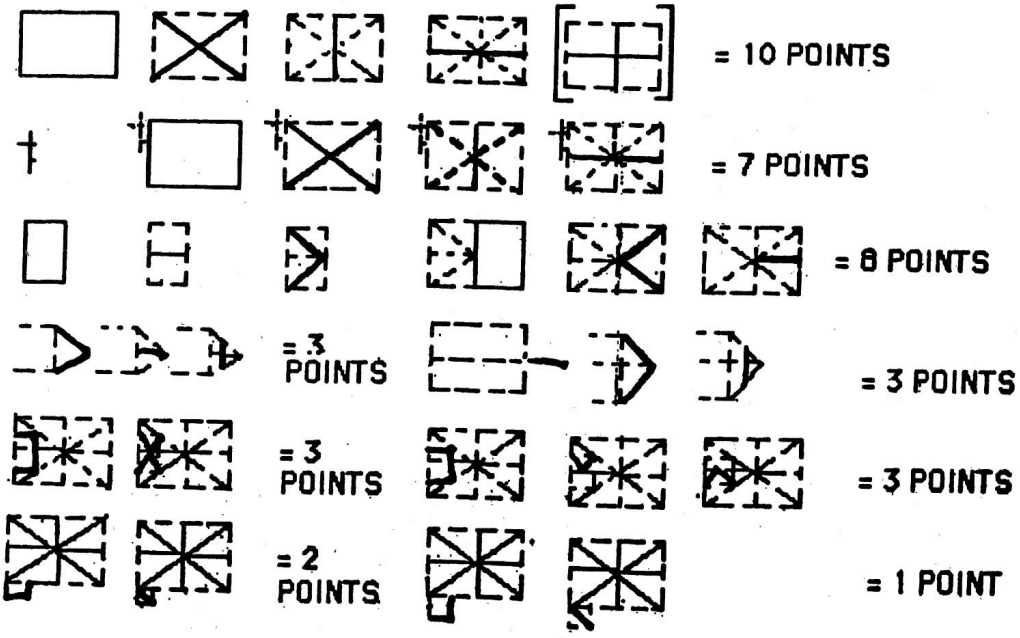
Correct	placed properly	2 points
	placed poorly	1 point
Distorted or incomplete but recognizable	placed properly	1 point
	placed poorly	½ point
Absent or not recognizable		0 points
Maximum		36 points

APPENDIX F: REY OSTERRIETH FIGURE SCORING SYSTEM

CONTINUATION SCORING-MAXIMUM 18 POINTS

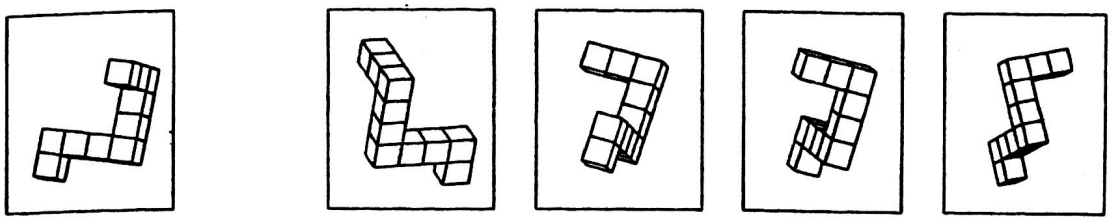


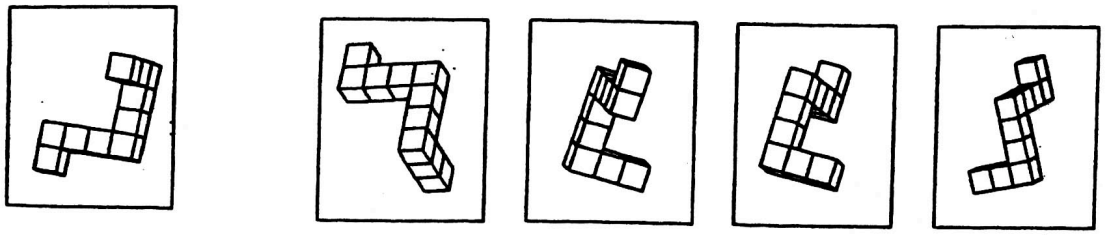
SYMMETRY SCORING- MAXIMUM 18 POINTS



STRATEGY TOTAL= CONTINUATION + SYMMETRY POINTS

APPENDIX G: SAMPLE STIMULI: REVISED VANDENBERG AND KUSE TEST OF MENTAL ROTATION





APPENDIX H: SALIVARY SAMPLING PROCEDURE

1. Subject is to avoid chewing gum, eating food, drinking, or brushing teeth for one hour prior to the collection of the sample.

2. Subject rinses his or her mouth thoroughly with cold water five minutes before collecting the sample.

3. One testing packet is used for each subject at each testing session. Each specimen packet contains 1 tube, 1 parafilm square, and a label. The examiner wears protective gloves during sample procedure.

4. Subject peels the printed paper from the parafilm square and slowly chews the clear, waxy part. The parafilm will stimulate saliva flow. Subject is not to put anything in his or her mouth other than the parafilm during sample collection.

5. Saliva is expressed into the collection tube until it is three-fourths full of liquid, not foam.

6. The parafilm is discarded. Parafilm is not to go into the collection tube.

7. The tube is capped securely and labeled with subject number, time, and date.

APPENDIX I: POST-TESTING QUESTIONNAIRE

1. You were asked to draw a figure and then recall it from memory. Please indicate the way you went about trying to remember the figure you had copied.

2. Which of the following best describes your approach to trying to remember the figure?

   a. I tried to picture the figure in my mind and then draw what I saw

   b. I named the various shapes and features to myself and then drew them to the best of my recollection.

   c. I did not use either of these approaches in trying to recall the figure.

3. You were asked to determine which two of four figures matched a target figure if the target figure were rotated. How did you go about solving these problems?

APPENDIX I: POST TESTING QUESTIONNAIRE

4. Which of the following best describes your approach to trying to determine which two figures matched the target figure?

   a. I pictured the object rotating as a whole.

   b. I matched parts of the target object to the four drawings and compared them.

   c. I used both of these strategies

   d. I didn't use either of these strategies.

5. Please circle which of these statements was true for you:

   a. The rotation task was easier to do when remembering the series of numbers rather than the visual sequence.

   b. The rotation task was easier to do when remembering the visual sequence rather than the series of numbers.

   c. I found no difference in difficulty on the rotation task whether I had to remember the visual or the numerical sequence.

6. Which, if any, of the tasks given during either or both sessions did you find particularly difficult or challenging?

7. Which, if any, of the tasks given during either or both sessions did you find particularly easy or unchallenging?

APPENDIX J: E-MAIL TO POTENTIAL PARTICIPANTS

Letter to potential volunteers

Thank you for expressing interest in becoming a participant in the research study entitled "The Impact of Sex, Family Handedness, and Hormone Levels on Cognitive Ability in Right-Handers." In order to enroll in the study, the first step is to complete a brief interview over the telephone. The purpose of this interview is to see if you qualify for the study and to schedule an appointment. I will also be happy to address any questions you might have at that time.

As a reminder, each participant is to complete two test sessions. You will be paid $5.00 for the first session and $10.00 for the second session. Participants who complete both sessions will also be entered into a random drawing for $100.00.

There are a number of criteria for volunteers in this study. Two of the primary requirements are as follows:

1) Participants must be right-handed

2) Participants must NOT be currently taking hormone supplements or be using hormonal forms of birth control (e.g. pill or patch)

If you meet these criteria and continue to be interested in participating in this study, please either send a return e-mail to this address (ead22@drexel.edu) or call me at (215) ___-____ between 9 am and 10 p.m. If leaving a message, it is helpful if you can let me know what time(s) are most convenient to call you for a screening.

Sincerely,

Elizabeth D'Andrea
Co-Investigator

APPENDIX K: RANDOM ASSIGNMENT SHEET FOR FEMALE PARTICIPANTS

Name	Subject No.	Fam Handedness	Start Phase	Test Form
		L	Menstrual	A
		L	Menstrual	B
		L	Follicular	A
		L	Follicular	B
		R	Menstrual	A
		R	Menstrual	B
		R	Follicular	A
		R	Follicular	B
		L	Menstrual	A
		L	Menstrual	B
		L	Follicular	A
		L	Follicular	B
		R	Menstrual	A
		R	Menstrual	B
		R	Follicular	A
		R	Follicular	B
		L	Menstrual	A
		L	Menstrual	B
		L	Follicular	A
		L	Follicular	B
		R	Menstrual	A
		R	Menstrual	B
		R	Follicular	A
		R	Follicular	B

APPENDIX L: TEST FORM I/SESSION 1

Subject #_____ Date_____

Sex_____ D.O.B._____

Major_____ Edu_____

1. **Informed consent**:

Reviewed _____

Questions 1) What is the purpose of this study?

2) What will be done?

3) What risks and discomforts may occur from participating in this study?

49. What benefits may the subject gain from participating in this Study?

Demonstrates understanding _____

Signed_____

Copy given to subject_____

3. Complete **Background Form** and **Handedness Inventory**_____

4. **Asher Test**: Note any History of visual difficulties including surgery and which eye is most impacted and age occurred _____ Subjects are seated across from the examiner and asked to hold their hands at face level with their palms facing them. They are then instructed to bring their hands together until all that can be seen is the examiner's nose. The eye aligned with the slit between their hands is noted as the dominant eye. This procedure is repeated twice.

Dominant eye Trial 1_____ Trial 2_____

APPENDIX L: TEST FORM I/SESSION 1

5. **Saliva test done**:

No eating, drinking, brushing teeth or gum for one hour_____

Rinse thoroughly with cold water five minutes before collecting sample_____

Subject peels printed paper from parafilm square and slowly chews the clear waxy part to stimulate saliva flow._____

Saliva expressed into collection tube until 3/4 full of liquid not foam_____

Time completed_____

Number placed on tube 1____00____ ____ (second digit 1=men/2=menstrual phase/3=midcycle phase) (fifth and sixth digit =subject number)

Label tube with subject number, time and date_____

You will now be asked to complete a number of short cognitive and motor tasks. Each of these tasks will be explained to you as we go along. It is important that you listen carefully to all the instructions I give you for each task. A few of the tasks will be done on a computer. For these tests, you will read the instructions presented on the screen. You may find some of these tasks difficult, but it is important for you to try your best. Please let me know if you have any questions o r concerns as we go along. Do you have any questions now?

6. **Digit Span**

7. Visual Span

APPENDIX L: TEST FORM I/SESSION 1

8. **Vandenberg and Kuse (Form A)**

Please look at these five figures. (show page one of test booklet and point out figures) ***Note that these are all pictures of the same object, which is shown from different angles. Try to imagine moving the object (or yourself with respect to the object) as you look from one drawing to the next. Here are two drawings of a new figure that is different from the one shown in the first five drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.*** (turn page to sample 1) ***Now look at this object. Two of these four drawings show the same object. Can you find those two and point them out to me.*** (Correct answer is first and third drawings). ***I am going to show you three more sample problems. Again, the target object is shown twice in each set of four alternatives from which you choose the correct ones. You will have thirty seconds to complete each item and point out the two correct choices.*** (answers: sample 2 = second and third; sample 3= first and fourth; sample 4= first and third)

When you do the test, please remember that for each problem set there are two and only two figures that match the target figure. Now I'm going to show you the first test item. Remember, you have thirty seconds to point out the correct figures.

(Answer A,B,C, or D)

1. (N) ---------- _____
2. (N) ---------- _____
3. (N) ---------- _____
4. (N) ---------- _____

APPENDIX L: TEST FORM I/SESSION 1

This next task will be a little more complicated. For these next items you will hear a series of digits that will be given about one per second. It is important for you to remember them by saying them to yourself continuously. When I show you the next page in this booklet, work on the mental rotation problem until you hear a second series of digits then let me know whether the second series was the same or different from the first series. It is important for you to remember the digits and to get them right.

		(Answer A,B,C, or D)		(Same or Different)
5. (Verb)	9-6-5-3-7-4-8	_____	9-6-5-3-7-4-8	_____
6. (Verb)	1-5-6-4-2-8-3	_____	1-5-6-4-2-7-3	_____
7. (Verb)	8-4-2-9-5-3-7	_____	8-4-1-9-5-3-7	_____
8. (Verb)	4-2-5-8-6-1-7	_____	4-2-5-8-6-1-7	_____

For these next items I will touch a series of dots at the rate of about one per second. It is important for you to remember the series by continuously visualizing it in your mind's eye. When I show you the next page in this booklet, work on the mental rotation problem until you see me touch a second series of dots then let me know whether the second series was the same or different from the first series. It is important for you to remember the series and to get it right.

		(Answer A,B,C, or D)		(Same or Different)
9. (Vis)	3-1-7-2-4-6-8	_____	3-1-7-2-5-6-8	_____
10. (Vis)	4-8-5-3-6-2-1	_____	4-8-5-3-6-2-1	_____
11. (Vis)	6-1-7-2-8-5-3	_____	6-1-7-2-8-5-3	_____
12. (Vis)	4-1-6-7-5-3-2	_____	4-1-6-8-5-3-2	_____
13. (Vis)	8-3-2-4-1-6-7	_____	8-3-2-5-1-6-7	_____
14. (Vis)	3-2-4-1-6-7-5	_____	3-2-4-1-6-7-5	_____
15. (Vis)	2-1-8-3-7-5-6	_____	2-1-8-3-7-4-6	_____
16. (Vis)	7-4-6-5-1-8-3	_____	7-4-6-5-1-8-3	_____

APPENDIX L: TEST FORM I/SESSION 1

For these next items you will once again hear a series of digits that will be given about one per second. Remember to keep rehearsing the digits. When I show you the next page in this booklet, work on the mental rotation problem until you hear a second series of digits then let me know whether the second series was the same or different from the first series. Again, it is important for you to remember the digits and to get them right.

		(Answer A,B,C, or D)		(Same or Different)
17. (Verb)	3-7-4-2-5-8-6	_____	3-7-4-2-5-8-6	_____
18. (Verb)	6-9-8-4-2-5-1	_____	6-9-8-4-2-5-1	_____
19. (Verb)	3-6-4-7-5-9-8	_____	2-6-4-7-5-9-8	_____
20. (Verb)	8-5-4-3-1-7-9	_____	8-5-4-2-1-7-9	_____

For these last items, I want you to solve each of the mental rotation problems as you did when we started this test. Remember you have thirty seconds to complete each of the items and point out the correct answers.

		(Answer A,B,C, or D)
21. (N)	----------	_____
22. (N)	----------	_____
23. (N)	----------	_____
24. (N)	----------	_____

APPENDIX L: TEST FORM I/SESSION 1

9. Finger Tapping Test (FTT)

Please place your right hand here, palm down, with fingers extended and your index finger placed on the key (demonstrate).***Tap as quickly as you can, moving only your index finger, not your whole hand or arm. Now you try*** (subject practice with right hand). ***Now I want you to tap the key as quickly as you can until I say stop. Ready. Begin.*** (ten seconds each trial/practice prior to first trial with left hand). Need five trials for each hand within a five point range up to ten trials. Alternate hands and give one to two minute rest after each hand has had three trials.

	Right	Left
1.	_____	_____
2.	_____	_____
3.	_____	_____
4.	_____	_____
5.	_____	_____
6.	_____	_____
7.	_____	_____
8.	_____	_____
9.	_____	_____
10.	_____	_____

APPENDIX L: TEST FORM I/SESSION 1

10. **Face Memory**

Show stimuli _____

Immediate recall _____

11. **Grooved Pegboard**

The pegboard is placed in mid-line with the subject so that the board is at the edge of the table and peg tray immediately above the board. ***This is a pegboard and these are the pegs. All the pegs are the same. They have a groove, that is, a round side and a square side and so do the holes in the board. What you must do is match the groove of the peg with the groove of the board and put these pegs into the holes like this.*** (examiner demonstrates by filling top row. Remove pegs and put into tray) ***When I say go, begin here and put the pegs into the board as fast as you can, using only your right hand. Fill the top row completely from this side*** (left) ***to this side*** (right)***. Do not skip any, fill each row the same way you filled the top row. Any Questions? Ready, as fast as you can go. Begin.*** Correct subject if he or she tries to use other hand or pick up more than one peg at a time. Do not pick up peg from floor. Re-use pegs if needed to complete.

Now I want you to do the same thing using your left hand. Start by filling the top row from this side ***(right)*** to this side ***(left)***. Any Questions? Ready, as fast as you can go. Begin.

Right Hand_____

Left Hand_____

APPENDIX L: TEST FORM I/SESSION 1

12. Controlled Oral Word Association

I will say a letter of the alphabet. Then I want you to give me as many words that begin with that letter as quickly as you can. For instance, if I say "B" you might give me bad, battle, bug…I do not want you to use words that are proper names such as Boston or Bob. Also, do not use the same word again with a different ending such as eat and eating. Any questions? Begin when I say the letter. The first letter is F. Go ahead.

Allow one minute for each letter. Mark off 15 second intervals.

	F	***A***	***S***
1)	_____	_____	_____
2)	_____	_____	_____
3)	_____	_____	_____
4)	_____	_____	_____
5)	_____	_____	_____
6)	_____	_____	_____
7)	_____	_____	_____
8)	_____	_____	_____
9)	_____	_____	_____
10)	_____	_____	_____
11)	_____	_____	_____
12)	_____	_____	_____
13)	_____	_____	_____
14)	_____	_____	_____
15)	_____	_____	_____
16)	_____	_____	_____
17)	_____	_____	_____
18)	_____	_____	_____

APPENDIX L: TEST FORM I/SESSION 1

13. Truck Test

    Administered_____

14. Face Memory

    Delayed Recall_____

15. Make Next appointment

    Next Appointment_____

16. Pay Subject ($5)

    Receipt Given_____

When you come in for your final testing session you will be asked to provide another saliva sample that will be used to test for estrogen and testosterone levels. Once again, in order to get an accurate reading, please try to avoid chewing gum, eating food, drinking, or brushing teeth for one hour prior to the test session. If you forget, you should still come to your appointment as scheduled—just notify the examiner. The next session will be somewhat shorter than the one today. At the end of that session, you will receive $10 and be entered into the random drawing for a chance to win $100.00. Do you have any questions?

APPENDIX M: FORM I (SESSION 2)

Subject #_____ Date_____

Sex_____ D.O.B._____

1. **Saliva test done**:

No eating, drinking, brushing teeth or gum for one hour_____

Rinse thoroughly with cold water five minutes before collecting sample_____

Subject peels printed paper from parafilm square and slowly chews the clear waxy part to stimulate saliva flow._____

Saliva expressed into collection tube until 3/4 full of liquid not foam_____

Time completed_____

Number placed on tube 1____00____ ____ (second digit 1=men/2=menstrual phase/3=midcycle phase) (fifth and sixth digit =subject number)

Label tube with subject number, time and date_____

You will now be asked to complete a number of short cognitive and motor tasks. Many of these tasks will be similar to the ones you did in the last testing session, but a few tasks will be different. As in the last session, each of these tasks will be explained to you as we go along. It is important that you listen carefully to all the instructions I give you for each task even if you remember the task from last time. A few of the tasks will be done on a computer. For these tests, you will read the instructions presented on the screen. You may find some of these tasks difficult, but it is important for you to try your best. Please let me know if you have any questions or concerns as we go along. Do you have any questions now?

50. Block Design

APPENDIX M: FORM I (SESSION 2)

3. **Information**

4. **Rey Osterrieth Figure**

(Hand subject blank paper and pencil)
I am going to show you a card on which there is a design that I would like you to copy on this sheet of paper. Please copy the figure as carefully as you can. If you think you have made a mistake, do not erase, just correct whatever you think is wrong. **(Examiner makes co-drawing)**

Copy_____

(Examiner removes stimulus figure, subject drawing, and co-drawing. Hand subject blank piece of paper) *Now I would like you to draw the figure from memory as carefully and completely as you can on this sheet of paper.*

Immediate Recall_____

5. **Digit Span**

6. Visual Span

APPENDIX M: FORM I (SESSION 2)

7. Vandenberg and Kuse (Use form B)

Please look at these five figures. (show page one of test booklet and point out figures) ***Note that these are all pictures of the same object, which is shown from different angles. Try to imagine moving the object (or yourself with respect to the object) as you look from one drawing to the next. Here are two drawings of a new figure that is different from the one shown in the first five drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.*** (turn page to sample 1) ***Now look at this object. Two of these four drawings show the same object. Can you find those two and point them out to me.*** (Correct answer is first and third drawings). ***I am going to show you three more sample problems. Again, the target object is shown twice in each set of four alternatives from which you choose the correct ones. You will have thirty seconds to complete each item and point out the two correct choices.*** (answers: sample 2 = second and third; sample 3= first and fourth; sample 4= first and third)

When you do the test, please remember that for each problem set there are two and only two figures that match the target figure. Now I'm going to show you the first test item. Remember, you have thirty seconds to point out the correct figures.

(Answer A,B,C, or D)

1. (N) ---------- _____

2. (N) ---------- _____

3. (N) ---------- _____

4. (N) ---------- _____

APPENDIX M: FORM I (SESSION 2)

This next task will be a little more complicated. For these next items you will hear a series of digits that will be given about one per second. It is important for you to remember them by saying them to yourself continuously. When I show you the next page in this booklet, work on the mental rotation problem until you hear a second series of digits then let me know whether the second series was the same or different from the first series. It is important for you to remember the digits and to get them right.

			(Answer A,B,C, or D)		***(Same or Different)***
5.	(Verb)	4-3-9-2-8-1-5	_____	4-3-9-2-7-1-5	_____
6.	(Verb)	7-9-3-2-6-8-4	_____	7-9-3-2-6-8-4	_____
7.	(Verb)	3-4-8-2-7-5-1	_____	3-4-8-2-7-5-1	_____
8.	(Verb)	7-2-9-8-3-4-6	_____	7-2-9-8-3-5-6	_____

For these next items I will touch a series of dots at the rate of about one per second. It is important for you to remember the series by continuously visualizing it in your mind's eye. When I show you the next page in this booklet, work on the mental rotation problem until you see me touch a second series of dots then let me know whether the second series was the same or different from the first series. It is important for you to remember the series and to get it right.

			(Answer A,B,C, or D)		(Same or Different)
9.	(Vis)	1-3-8-7-6-5-2	_____	1-3-8-7-6-5-2	_____
10	.(Vis)	4-1-2-8-7-6-5	_____	4-1-3-8-7-6-5	_____
11.	(Vis)	6-2-1-4-8-3-7	_____	5-2-1-4-8-3-7	_____

APPENDIX M: FORM I (SESSION 2)

12.	(Vis)	8-1-3-7-2-6-4	_____	8-1-3-7-2-6-4	_____
13.	(Vis)	4-5-3-6-8-7-1	_____	4-5-3-6-8-7-1	_____
14.	(Vis)	2-8-1-4-3-7-6	_____	2-8-1-5-3-7-6	_____
15.	(Vis)	7-5-8-3-4-2-1	_____	7-5-8-3-4-2-1	_____
16.	(Vis)	3-1-7-8-2-4-6	_____	3-1-7-8-2-4-5	_____

For these next items you will once again hear a series of digits that will be given about one per second. Remember to keep rehearsing the digits. When I show you the next page in this booklet, work on the mental rotation problem until you hear a second series of digits then let me know whether the second series was the same or different from the first series. Again, it is important for you to remember the digits and to get them right.

			(Answer A,B,C, or D)		(Same or Different)
17.	(Verb)	4-9-1-3-5-7-2	_____	4-8-1-3-5-7-2	_____
18.	(Verb)	9-8-6-1-3-5-7	_____	9-8-6-1-3-4-7	_____
19.	(Verb)	6-2-9-4-8-1-3	_____	6-2-9-4-8-1-3	_____
20.	(Verb)	5-7-8-3-1-4-2	_____	5-7-8-3-1-4-2	_____

For these last items, I want you to solve each of the mental rotation problems as you did when we started this test. Remember you have thirty seconds to complete each of the items and point out the correct answers.

			(Answer A,B,C, or D)
21.	(N)	----------	_____
22.	(N)	----------	_____
23.	(N)	----------	_____
24.	(N)	----------	_____

APPENDIX M: FORM I (SESSION 2)

8. Finger Tapping Test (FTT)

Please place your right hand here, palm down, with fingers extended and your index finger placed on the key (demonstrate).***Tap as quickly as you can, moving only your index finger, not your whole hand or arm. Now you try*** (subject practice with right hand). ***Now I want you to tap the key as quickly as you can until I say stop. Ready. Begin.*** (ten seconds each trial/practice prior to first trial with left hand). Need five trials for each hand within a five point range up to ten trials. Alternate hands and give one to two minute rest after each hand has had three trials.

	Right	Left
1.	_____	_____
2.	_____	_____
3.	_____	_____
4.	_____	_____
5.	_____	_____
6.	_____	_____
7.	_____	_____
8.	_____	_____
9.	_____	_____
10.	_____	_____

APPENDIX M: FORM I (SESSION 2)

9. **Face Memory**

Show stimuli _____

Immediate recall _____

10. **Grooved Pegboard**

The pegboard is placed in mid-line with the subject so that the board is at the edge of the table and peg tray immediately above the board. ***This is a pegboard and these are the pegs. All the pegs are the same. They have a groove, that is, a round side and a square side and so do the holes in the board. What you must do is match the groove of the peg with the groove of the board and put these pegs into the holes like this.*** (examiner demonstrates by filling top row. Remove pegs and put into tray) ***When I say go, begin here and put the pegs into the board as fast as you can, using only your right hand. Fill the top row completely from this side*** (left) ***to this side*** (right)***. Do not skip any, fill each row the same way you filled the top row. Any Questions? Ready, as fast as you can go. Begin.*** Correct subject if he or she tries to use other hand or pick up more than one peg at a time. Do not pick up peg from floor. Re-use pegs if needed to complete.

Now I want you to do the same thing using your left hand. Start by filling the top row from this side ***(right)*** *to this side* ***(left)****. Any Questions? Ready, as fast as you can go. Begin.*

Right Hand_____

Left Hand_____

APPENDIX M: FORM I (SESSION 2)

11. *Controlled Oral Word Association*
I will say a letter of the alphabet. Then I want you to give me as many words that begin with that letter as quickly as you can. For instance, if I say "B" you might give me bad, battle, bug…I do not want you to use words that are proper names such as Boston or Bob. Also, do not use the same word again with a different ending such as eat and eating. Any questions? Begin when I say the letter. The first letter is C. Go ahead.

Allow one minute for each letter. Mark off 15 second intervals.

	C	***F***	***L***
1)	_____	_____	_____
2)	_____	_____	_____
3)	_____	_____	_____
4)	_____	_____	_____
5)	_____	_____	_____
6)	_____	_____	_____
7)	_____	_____	_____
8)	_____	_____	_____
9)	_____	_____	_____
10)	_____	_____	_____
11)	_____	_____	_____
12)	_____	_____	_____
13)	_____	_____	_____
14)	_____	_____	_____
15)	_____	_____	_____
16)	_____	_____	_____
17)	_____	_____	_____
18)	_____	_____	_____

APPENDIX M: FORM I (SESSION 2)

12. Truck Test

Administered_____

13. Face Memory

Delayed Recall_____

14. Rey Osterrieth Figure Delay Recall

(Hand subject pencil and blank piece of paper).*Do you remember the design I had you copy awhile ago? I would like you to draw it again from memory as carefully and completely as you can on this sheet of paper*.

Delayed Recall completed_____

15. Post-Testing Questionnaire_____

16. Pay Subject ($10.00)

Receipt Given_____

Fill out information for lottery drawing_____

Confirm contact information for follow-up/lottery drawing_____

17. Follow up needed? (late follicular phase women only) yes_____ no_____

Thanks for participation

APPENDIX N: OVERVIEW OF MEASURES AND PROCEDURES

Screening/group assignment
Qualifying Questionnaire
Family Handedness Questionnaire

Test Session #1
Informed Consent
Saliva Testing
Background Information Form
The Handedness Inventory
Asher Test
WAIS-R Digit Span Subtest
WMS-R Visual Span Subtest
Mental Rotation
    Verbal Digit Memory Task
    Visual Memory Task
Finger Tapping
Penn Face Memory Test (Encoding and Immediate Recall)
Grooved Pegboard
Controlled Word Association Test
Truck Test
Penn Face Memory Test (Delayed Recall)

Test Session #2
Saliva Testing
WAIS-R Block Design Subtest
WAIS-R Information Subtest
Rey-Osterrieth Complex Figure (Copy and Immediate Recall)
WMS-R Visual Span Subtest
Mental Rotation
    Verbal Digit Memory Task c
    Visual Memory Task
Finger Tapping
Penn Face Memory Test (Encoding and Immediate Recall)
Grooved Pegboard
Controlled Word Association Test
Truck Test
Penn Face Memory Test (Delayed Recall)
Rey-Osterrieth Complex Figure (Delayed Recall)
Post-Testing Questions

Follow-up (women starting in menstrual phase only). Date of the first day of their first menstrual cycle following session two was verified.

APPENDIX O: EXPECTED HORMONE RANGES

	Estradiol-Saliva (pg/ml)
Female menstrual phase	0.5-5.0
Female late follicular	2.0-7.0
Male	0.5-1.5

	Testosterone, Free-Saliva (pg/ml)
Female	5-35
Male	60-125

*Source: Pharmasan Labs

VITA

Elizabeth Ann D'Andrea was born on October 9, 1964, in East Orange, New Jersey. She grew up in western Massachusetts, and graduated from Taconic High School in 1982. Elizabeth began her undergraduate studies at Vanderbilt University in Nashville, Tennessee. She received a B.A.in human development at Antioch College in 1987. While at Antioch, Elizabeth completed a thesis examining public perceptions of people with borderline personality disorder. She also completed five undergraduate internships including work at Five Acres Boys and Girls Society of Los Angeles County and The Menninger Foundation in Topeka, Kansas. Elizabeth worked in women's health in San Diego, California until beginning graduate work at Drexel University in Philadelphia, PA. While at Drexel, she worked at Bryn Mawr Rehabilitation Hospital and the Philadelphia VA Hospital. She was also the recipient of a Drexel University Teaching Assistant Excellence Award. Elizabeth received her Master of Science degree from Drexel in 1998 and completed a pre-doctoral internship at the East Orange VA Hospital in 1999, focusing on neuropsychological assessment, psychological treatment of chronically and terminally ill patients, and PTSD treatment. She has been married since 1994 and has two children.